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BASELINE NOISE MEASUREMENTS OF ARMY HELICOPTERS

VOLUME I

PROGRAM STUDY AND FIELD TESTS

By

David Brown

July 1971

EUSTIS DIRECTORATE

U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY

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13. ABSTRACT

This report describes a study of the methods by which noise data of Army helicopters can be measured, stored, and analyzed in a consistent and accurate manner to form a baseline noise data bank. A review is made of the characteristics of helicopter noise that create particular problems in measurement and recording, and current acquisition techniques are discussed in terms of these problems. A field test program is described, in which the noise of five Army helicopters was measured for hover and flyover modes of operation. Sample data, obtained by analysis of the noise records, are presented in Volume I of this report. Volume II is a compilation of analyzed data for each of the five helicopter types. As a result of the study, a draft acoustic measurement specification is presented which defines the requirements on helicopter noise data acquisition and analysis for Army data-bank storage.

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FORT EUSTIS, VIRGINIA 23604

This report was prepared by Wyle Laboratories under the terms of Contract DAAJ02-70-C-0025. It consists of a study to develop noise measurement techniques, details of a field test to measure the external noise signatures of five helicopters, and a draft measurement specification.

The object of this contractual effort was to acquire a data bank of updated baseline noise signatures for five classes of tactical helicopters and to prepare specifications to ensure consistency in obtaining and reducing helicopter noise data. The aircraft measured were the OH-6A, UH-1B, CH-47B, AH-1G, and CH-54A.

The recommendations contained herein are concurred in by this Dire torate. This concurrence is limited to the technical feasibility of obtaining accurate and comprehensive baseline noise data for data bank useage.

This program was conducted under the technical direction of Mr. Bill W. Scruggs, Jr., Safety and Survivability Division, Eustis Directorate.

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July 1971

BASELINE NOISE MEASUREMENTS OF ARMY HELICOPTERS

VOLUME I

PROGRAM STUDY AND FIELD TESTS

Final Report

Wyle Research Staff Report WR71-4

By

David Brown

Prepared by

Wyle Laboratories
Hampton, Virginia

for

EUSTIS DIRECTORATE
U. S. ARMY
AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

ABSTRACT

This report describes a study of the methods by which noise data of Army helicopters can be measured, stored and analyzed in a consistent and accurate manner to form a baseline noise data bank. A review is made of the characteristics of helicopter noise that create particular problems in measurement and recording, and current acquisition techniques are discussed in terms of these problems. A field test program is described, in which the noise of five Army helicopters was measured for hover and flyover modes of operation. Sample data, obtained by analysis of the noise records, are presented in Volume I of this report. Volume II is a compilation of analyzed data for each of the five helicopter types. As a result of the study, a draft acoustic measurement specification is presented which defines the requirements on helicopter noise data acquisition and analysis for Army data-bank storage.

FOREWORD

This work was performed by Wyle Laboratories for the Eustis Directorate of the U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, under Contract DAAJ02-70-C-0025, Task 1F162203A14801. The work was conducted under the technical cognizance of Mr. Bill W. Scruggs, Jr., of the Eustis Directorate.

The technical coordination of this work with a parallel study of "Helicopter Aural Detectability" for the Eustis Directorate has been supervised by J. B. Ollerhead of Wyle Laboratories. Major contributors to the development of data analysis programs were J. B. Ollerhead of Wyle Laboratories and Mr. A. C. Jolly, consultant.

Mr. Bill W. Scruggs, Jr., of the Eustis Directorate was responsible for the field program logistics, and provided valuable technical assistance during the field tests.

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1.0 INTRODUCTION

1.1 BASIC OBJECTIVES

The present work is part of a continuing program of research and development sponsored by the Eustis Directorate of the U. S. Army Air Mobility Research and Development Laboratory into safety and survivability criteria for the tactical deployment of Army flight vehicles. The work reported herein is specifically related to the radiated noise characteristics of helicopters and is aimed at the compilation of a data bank of such information at the Eustis Directorate.

In general, the quantative assessment of the aural detectability and related hazard potential of various helicopter types in various modes of deployment depends to a great extent on the quality of the data available and the conditions under which the data were acquired and recorded. In many cases, such assessments are, of necessity, based on data obtained by different agencies employing a wide range of techniques, systems, and test procedures. The resulting incompatibility of reduced data has limited the accuracy of subsequent interpretive and applications processing to such a degree that the derivation and employment of a standardized practice for U. S. Army noise measurement programs is believed to be essential for future safety and survivability analysis of Army helicopters.

The objectives of the present work are therefore to establish practical, state-of-the-art procedures by which helicopter noise can be measured and recorded accurately, consistently, and with sufficient resolution that data obtained under different programs over a period of years can be regarded as reliable and compatible. This report describes the efforts conducted to achieve these objectives. The basic characteristics of helicopter noise are discussed in terms of measurement and and analysis requirements, and a review of instrumentation capabilities is made with particular reference to these requirements. A program of noise measurement on five U. S. Army helicopter types is described and data analysis has been conducted on the acquired noise records. The reduced data is presented in summary form in Volume II of this report. Volume I contains typical examples of these analyzed results. Finally, a draft noise measurement specification is presented. This specification is partly based on the procedures of References 1 and 2, but is specifically directed towards achieving a standardized method for the measurement and recording of helicopter noise for the Eustis Directorate data bank storage.

1.2 THE NATURE OF THE PROBLEM

The measurement of noise by modern methods involves at least two basic steps: the conversion of the sound pressure signal to an analagous electrical signal, and the conversion of the electrical signal to a convenient quantity for interpretive usage. The latter may simply be a reproduction of the original sound field for auditory stimulation, an oscillogram of the sound pressure amplitude, an average power spectral density distribution, etc. Because it is usually inconvenient to perform data reduction "on site", and because the entire analysis requirements are usually unspecified at the acquisition stage, an intermediate step of recording the electrical signal in permanent form on magnetic tape for later analysis is normally introduced. The two stages of noise measurement then become (1) recording an electrical analog of the sound pressure history, and (2) analyzing the stored signal. The nature of the latter step depends entirely on the purpose for which the measured data are required and may be qualitative or quantitative. However, this is almost completely independent of the first step which is the primary subject of this report. The first major problem is to acquire and record an electrical signal which is completely linearly related to the sound pressure history. Practical difficulties are all associated with various sources of nonlinearities.

Manv studies have been made of the problem of recording and analyzing aircraft noise, and several recommended procedures have been formally documented. Of these, the standards imposed by Part 36 of the Federal Aviation Regulations (Reference 1) are the most explicit in defining measurement and analysis methods, but are specifically directed to general (fixed-wing) aircraft noise evaluations for certification purposes. Conversely, the recommended procedures published by the Society of Automotive Engineers (Reference 2) provide a more general guide to noise measurement practices and deliberately avoid detailed specification of test program content. In adapting these and other documented standards to the present case of helicopter noise measurement, consideration must be given to the fact that the sound generated by helicopters is characteristically different from that of fixed-wing aircraft. The origin of this distinctive signature can be traced to the main lifting rotor(s), which ranks highest among the various noise sources on a helicopter. Depending on the rotor configuration, mode of operation, and the field point at which it is heard, the character of rotor noise may be described as "throbbing," "banging," "slapping," "swishing," or possibly as a combination of these. For noise measurement purposes, the most significant differences can be defined in terms of the frequency and amplitude characteristics of the sound. Due to relatively low

rotational speeds (rpm), low blade numbers and high blade-tip Mach numbers at which rotors operate, the sound generated is usually highly pulsatile with a fundamental frequency below 50 Hz, which is the normally accepted lower cutoff frequency for conventional aircraft noise analysis. This low frequency content often controls the overall level of helicopter noise and consequently must be included in the data acquisition. The problems associated with this are fully discussed in Sections 2.0 and 3.0 of this report.

While other noise generators, such as tail rotors, transmission systems, and power plant, contribute little to the measured overall sound level of helicopters, they can be aurally distinguished in the signature at particular observation points around the helicopter. Further, as considerable research and design effort is being concentrated on reducing the main rotor noise of helicopters, future designs may have a noise signature that is dominated by these subsystems. It is therefore desirable to include such sound contributions in the recordings of present vehicle noise.

Each noise generator contributes sound of different intensity, directivity, and frequency content. At any (large) radius from the helicopter, the noise would be observed to change in character according to the polar angle from the flight axis. This becomes further complicated by the fact that a ground-based observer is stationary and will simultaneously experience this change in directivity and a change in amplitude and frequency due to the vehicle's velocity of approach or pass. Thus, the definition of sound, and its measurement and analysis, must be identified by the location of observation with respect to the vehicle at all time instances during the period of subjection or measurement. With this information, the nature of the sound and its correlation to the source mechanisms can be usefully studied. The descriptive terms commonly used for helicopter noise give an indication of the frequency content. In general, the sound from the main rotors is either pulsatile or modulated random. The former has a sharp-fronted pulse-wave format which contains many discrete-frequency harmonics (tones) at multiples of the blade-passage frequency (Bpf).

$$\text{Bpf (Hz)} = N \times B = \omega_0/2\pi$$

where B is the number of rotor blades and N is the rotor speed in revolutions per second. The analysis of the pulsatile sound into its harmonic content provides a large quantity of interpretive information on the noise, such as the physical properties of its source, its propagation efficienty over large distances (low frequencies propagate more efficiently), and its aural detectability, annoyance, and speech-

masking effects. Of primary importance to the safety aspects of military deployment is, of course, the aural detectability of helicopters and this has been studied in detail by Loewy (Reference 3) and most recently by Ollerhead (Reference 4). In the latter work, consideration was also given to the phase relationships of the harmonic content of pulsatile signals. These relationships are an essential part of the signal as they determine the manner in which the harmonics are contained in the pulse shape. This is simply illustrated by

$$p(t) = \sum_{n=1} p_n \cos (n\omega_o t + \phi_n)$$

where p(t) is the time history of the sound pressure, p_n is the amplitude of the nth harmonic and ϕ_n is the phase shift relative to an arbitrary (zero) reference. Although little is known about the changes in phase which occur as an acoustic signal and is propagated over large distances, it is shown in Reference 4 that the identifying aspects of the sound are affected by the phase content and therefore this content should be, ideally, retained in the recorded analog of the measured sound.

Random noise contains sound pressure fluctuations which are non-periodic and are describable only in a statistical sense. The frequency spectrum is continuous (i.e., no harmonic "spikes") over a wide frequency band. This type of noise is generated by all mechanisms to some extent, but is usually of secondary importance for rotating mechanisms with higher tonal radiation. In the case of helicopter rotors, this random noise is generated by high energy turbulence in the blade boundary layer and wake. At some distance from the rotor, the random noise is observed to be modulated by the blade rotation; hence, a "swishing" characteristic is noticeable at short distances from a helicopter. In general, this content of helicopter noise does not impose any additional requirements on a measurement system designed to account for the rotor harmonic and subsystem noise.

1.3 NOISE MEASUREMENT, STORAGE, AND ANALYSES

While many new analysis tools are becoming available, particularly for real-time, on-line, spectral and statistical evaluations, the most versatile approach to the general-purpose data acquisition is to record such data on magnetic tape and conduct the analyses by digital or analog methods at a later date. The sound history is therefore measured at various field locations simultaneously by a suitable array of microphones that convert the respective histories to electrical signals. Each signal is then transmitted to a recording station and requires

processing before input to the tape recorder to ensure that the range capabilities of this component are fully exploited. Here, some preliminary monitoring or analysis is essential, and should be limited to those features relevant to the acquisition process.

The sound pressure time history obtained at each microphone station during a helicopter's approach and flyby can be described by the following characteristic data:

1. The time history of the overall sound pressure level (OASPL) or of some other single defining variable quantity such as the effective perceived noise level (EPNL).

2. Frequency spectra, averaged over acceptable time intervals, at specified time increments during the approach and flyby.

3. Maximum crest factor and pulsatile rise-rates during the time period of interest.

4. Harmonic-phase data during the history.

As it would be both laborious and impractical to monitor all of these characteristics during the measurement program to ensure that the recording process is within acceptable accuracy limits, the alternative procedure of monitoring only particular aspects of the signal is accepted as the best approach. It is therefore imperative that the quantity monitored adequately describe the signal in relation to the capabilities of the measurement and recording systems. These capabilities are usually defined, in terms of distortion tolerances, by the following terms*:

1. Frequency response
2. Dynamic range
3. Signal-to-noise ratio
4. Phase distortion
5. Harmonic distortion
6. Transient response (rise-rate)
7. Directivity

*The above terminology is by no means standard in system specifications nor does it provide a total definition of response limitations. However, as will be shown in this report, these characteristics are generally accepted as defining the dominant limitations of acoustic test equipment.

As previously noted, once the noise data are stored as retrievable analogs of the original sound pressure histories, many forms of analysis can usually be applied to collapse the data to a more readily interpretable quantity. However, in the case of flyover noise data, certain limitations are incurred by the influence of the source motion relative to the observer, and by the rapid variance in level observed as the polar incidence is changed around the helicopter (directivity). The resulting "nonstationarity" of the signal (that is, variance in statistical properties of the signal with translations in time) requires that particular care be taken in both analysis and interpretive tasks. Studies to combine the advanced state of computer technology and the fundamental principles of analysis are currently being conducted, but leave open questions on the form of averaging procedures to be applied to pulsatile data. A critical, detailed assessment of these analysis procedures has been conducted by Ollerhead (Reference 4) with particular reference to helicopter aural detectability.

The helicopter is unique also in the respect that a genuine flight condition (hover) will provide a quasistationary noise signal at a fixed ground location. This enables a much more accurate assessment of the harmonic content for that flight condition only, and offers a source of meaningful data for interpretive study. In general, therefore, the narrow band processing is usually reserved for stationary (hover) data, and larger bandwidths, such as 1/3 octave, are applied in real-time analysis of flyover noise signals.

1.4 SUMMARY

The low frequency pulsatile nature of helicopter noise requires measurement techniques not adequately defined by existing documents. In order to maintain compatibility in data evaluation, the present study is aimed at reviewing measurement techniques and determining a practical approach to the standardization of helicopter noise data acquisition procedures. A survey of current noise measurement procedures has been conducted by discussion with other Government agencies (National Aeronautics and Space Administration, Air Force Flight Dynamics Laboratory) and instrumentation suppliers. Specialized system designs have been offered by the latter, based on requirements specified for the helicopter noise problem. Two of these systems have been used in a field program of noise measurement on five Army helicopters. The technical reviews and the measurement and analysis programs are described in the following sections of this report.

2.0 HELICOPTER NOISE

2.1 PREDOMINANT MECHANISMS AND RELATED PARAMETERS

Previous studies of helicopter noise (References 5, 6, and 7) have identified the predominant generating mechanisms and derived procedures for the prediction of sound levels radiated by each of these mechanisms. The major noise components in a typical helicopter sound spectrum are as follows:

- Main rotor harmonics
- Tail rotor harmonics
- Rotor vortex (broadband) noise
- Transmission gearbox noise
- Power plant compressor harmonics
- Power plant exhaust

In the far field, the rotor systems essentially define the overall sound pressure level and the subjective noise characteristics of most helicopters, as may be demonstrated by Figure 1 (from Reference 6). In this illustrative case, the maximum spectral level occurs at low order main-rotor blade passage harmonics, which are at very low frequencies. The spectrum then decays with increasing frequency as the main rotor harmonics diminish until the frequency regime of the tail rotor rotational noise is encountered. Further along the frequency scale, the vortex (broadband) and power plant transmission system noise contributions are encountered. In terms of the audible signature, all of these components are not readily distinguishable at all positions around the helicopter. What is heard at most positions is the highly pulsatile sound that emanates from the main rotor. Although the fundamental frequency is in a region of low auditory sensitivity, the ear senses the modulation at this frequency and recognizes the harmonic content only in the respect that it forms the shape of the sound pulsations. At very large distances from the helicopter, the higher frequency components of the spectrum are attenuated in the propagation process and the sound is better described as a low frequency "throbbing". At certain polar orientations, the tail rotor is noted to predominate and sounds more like a conventional propeller, of higher frequency than the main rotor noise. Again, the blade passage frequency characterizes the noise, and the higher harmonics contribute to the qualitative aspects of the tail rotor noise. The significance of gearbox and compressor noise is usually limited to the relatively near field and to the cabin area. Each of these noises is higher in frequency than the rotor noise and produces the "whine" that is distinguishable around a helicopter about to lift off.

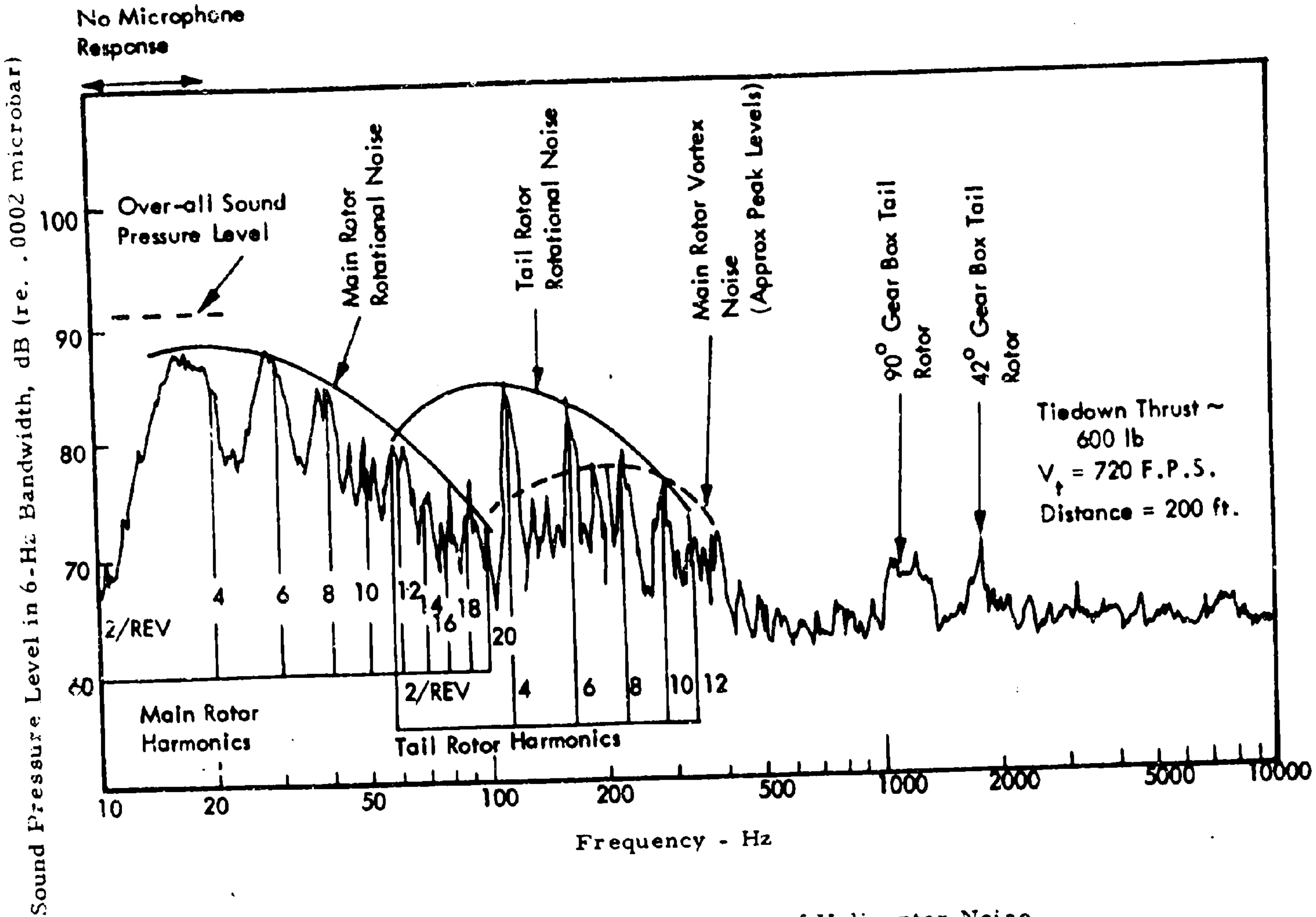

Figure 1. Typical Frequency Spectrum of Helicopter Noise.

Although the above comments on the predominant mechanisms of sound generally apply to most current helicopter types, many present studies aimed at rotor noise reduction and thrust augmentation to achieve higher flight velocities can be expected to shift the emphasis of these mechanisms in subjective noise assessment. When this becomes a reality, information on the noise characteristics of these other mechanisms will be in demand, and the measurement and storage of such noise data from present helicopter types will be of paramount importance. In both the engineering and subjective response areas of acoustics, the operating conditions of the generating mechanisms are of prime significance. To the noise-reduction specialist, the sound history provides only partial information. The specific operating conditions of each mechanism are essential to an understanding of the problem. Similarly, the subjective assessment of aural detectability or tactical deployment must be interrelated to the operational mode anticipated in particular roles, which in turn should be related to the mechanical and aerodynamic parameters of flight. It is therefore essential that the storage of noise data be accompanied by a full compilation of the operating parameters pertinent to each measurement flight. Part of this information will be more related to the basic vehicle design than to the flight condition, while the parameters of flight operation can be obtained from the cabin instrumentation. In a general noise measurement program, the installation of specialized instrumentation for research purposes is not anticipated and the relevant information can be categorized as follows:

1. Vehicle Design Data:
   (a) Vehicle type, engine type.
   (b) Main and tail rotors:
   Diameter, blade number, gear ratio, airfoil section, blade area, disc area, taper ratio, twist, tip shape.
   (c) Power plant:
   (Turbine) rated SHP, rated turbine speed (maximum), 100% compressor speed, compressor diameter, first-stage compressor blade number, IGV number, (piston) rated BHP, cylinder number, displacement, exhaust diameter.
   (d) Transmission:
   Gear ratios, gear tooth numbers.
2. Flight Operation Data:
   (a) Flight conditions:
   Velocity, altitude, flight path, basic vehicle weight, c.g. position, estimated thrust.
   (b) Cabin instrumentation:
   Pressure altitude, indicated airspeed, total air

temperature, torque pressure, rotor speed (rpm), compressor speed (%), pressure ratios (manifold or inter-turbine stage), exhaust gas temperature (egt), fuel weight.

In addition, meteorological and tracking information must be included in the identification data.

2.2 MEASUREMENT REQUIREMENTS

2.2.1 Measurement and Storage of Noise Data

While the ideal requirement of a data acquisition program is basically that the stored data be retrievable as exact analogous replica of the original physical phenomenon, the practical limitations of hardware systems determine the actual degree of accuracy and resolution of the acquisition and storage processes. Nevertheless, a set of basic objectives must be stated prior to a system design and must be used as guiding criteria in the acquisition program. For ease of interpretation and to avoid ambiguity, these requirements are best stated in terms of the overall system frequency response, dynamic range, distortion, etc., as listed in Section 1.3. The following discussions are therefore based on the desired capabilities of a measurement system that will allow later analysis and interpretive study of the most significant characteristics of helicopter noise.

2.2.2 Frequency Response

The frequency response is usually defined as that frequency range over which a system responds, within specified limits of nonlinearity, to a constant amplitude, swept frequency input signal. The limits in nonlinearity are specified in ± dB units relative to the known input signal amplitude (rms). For helicopter noise measurements, the lowest frequency of interest is determined by the blade passage frequency of the main rotor, but it is also known that the disc frequency (the main rotor revolutions per second) may contain sound energy resulting from unbalance of the blade loadings. A survey of the main rotor disc and blade passage frequencies of the helicopter types to be examined in this program, as listed in Table I, suggests that the lowest frequency of interest is in the order of 3 Hz. When practical, therefore, the lower limit of the system frequency response should be less than this value. However, if a compromise must be made in other significant capabilities to achieve this low frequency, then the required lower limit should be taken as one-half of the blade passage frequency. The

latter criteria will allow analytical resolution of the blade passage sound amplitude.

TABLE I. MAIN-ROTOR FREQUENCIES OF HELICOPTERS

Helicopter Type	Disc Frequency (rps)	Blade Number	Blade Passage Frequency (Hz)
UH-1B	5.43	2	10.86
AH-1G	5.40	2	10.80
OH-6A	7.83	4	31.32
CH-47B	3.75	3	11.25
CH-54A	3.18	6	19.08

The upper limit of frequency response for helicopter noise measurements is more difficult to define due to lack of available information on the higher frequency components. Available records of helicopter noise are limited in the range of sound pressure level that may be analyzed from the data, and it is well known that in the far field (especially), the high frequencies may be of the order of 40 to 50 dB below the overall sound pressure level. For subjective noise studies, however, it is desirable to obtain some information on these components, and it is usual to require an upper frequency response limit of at least 15 kHz. This value is regarded as a requirement in the present work.

Over this frequency range it is necessary to specify a tolerance of response nonlinearity. In noise-reduction applications, a tolerance of $\pm$ 1 dB is regarded as adequate, but in subjective detection studies the criterion usually employed is that an increase in level of 0.5 dB will allow perception of the signal against the background (ambient) noise. For most practical purposes, these requirements may be relaxed to the following:

Frequency response: 5 Hz to 15 kHz ($\pm$ 1 dB)
20 Hz to 10 kHz ($\pm$ 0.5 dB)

2.2.3 Dynamic Range and Signal-to-Noise Ratio

The range of signal levels that can be linearly processed by an equipment item is usually specified as the "dynamic range" of the item. In some cases, for example microphones, the dynamic range is specified in dB sound pressure level. For other items where the electrical signal level is adjustable, the range is specified as the "signal-to-noise ratio" and is referenced to the nominal input level appropriate to the adjustment setting. In almost all cases, the lower limit of the dynamic range is determined by the inherent noise floor of the electronic system.

The dynamic range system should satisfy two primary requirements:

1. It should accommodate all frequency components of interest in a sound spectrum at any "instant" of time.

2. It should accommodate the highest instantaneous amplitude to be encountered in the record and the lowest component amplitude of interest in the entire history, as recorded over a specified flight path distance.

In order to determine the practicability of these desired capabilities, reference was made at the preliminary stage of this program to real-time 1/3 octave band flyover data obtained on three of the target aircraft listed in Table I. The spectral characteristics of one of these helicopter types are shown in Figure 2* which indicates:

- Band levels at the time of maximum overall level.
- Band levels at 7 seconds prior to maximum overall level.
- Maximum band levels during the flyover history.

The spectral decay rate of about 7 dB per octave, indicated in Figure 2, was found to be typical of each helicopter type, as was the noticeable leveling of the spectra at about 45 dB below the overall level. While the former characteristic is a real effect in helicopter noise, the latter is probably due to the dynamic range limitation of the recording equipment and is indicative of the noise floor of the system. It is well known that the major limitation of magnetic tape recording equipment, especially recorders designed for acquisition of low frequency signal content, is the signal-to-noise range available. An acquisition range of about 45 dB is common in such equipment. To overcome this, a method of preemphasis of the signal prior to recording is often used.

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*The basic recorded histories were obtained for use in detection studies and are uncalibrated for security classification purposes.

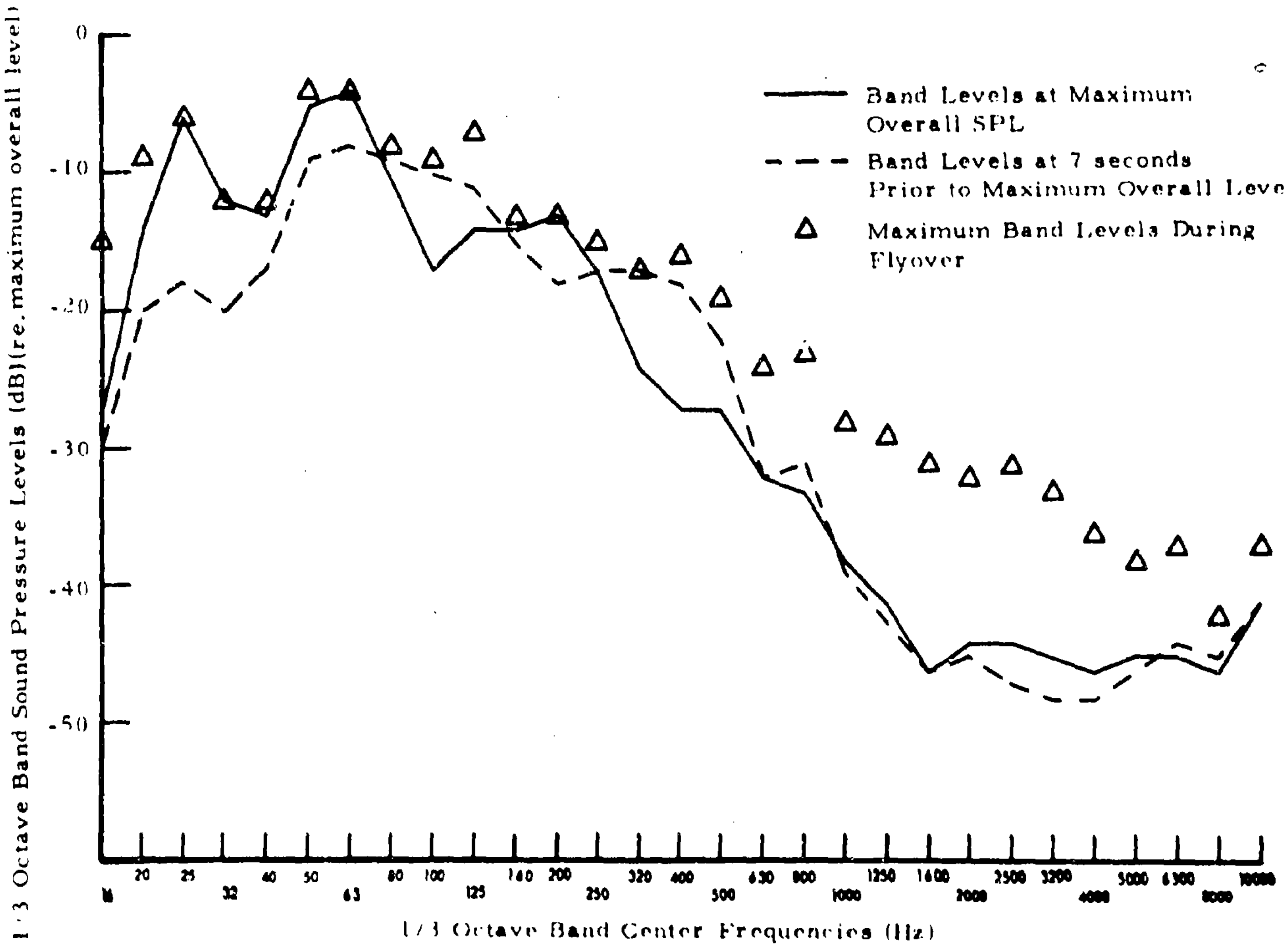

Figure 2. Real-Time Analyzed Spectra of Helicopter Flyover Noise.

As previously mentioned, the propagation distance between the noise source and the measurement point has a significant effect on the spectrum shape due to increased atmospheric attenuation at higher frequencies. The effect of this attenuation on a 7-dB-per-octave roll-off spectrum is illustrated in Figure 3 for various distances between source and measurement point. The atmospheric dispersion rates used in this figure are obtained from Reference 9. By superimposing a 45-dB limit on the spectral lines it becomes apparent that at large approach distances of a helicopter from the measurement point, the acquired spectrum frequency range is severely restricted. At the 10,000-foot approach, for example, the upper frequency limit is only 500 Hz. This can be extended to 1000 Hz by increasing the dynamic range to 60 dB relative to the overall level, which is a practical objective for preemphasis methods as will be discussed in Section 3.4. If it is assumed that noise from the secondary sources, such as the power plant and transmission systems, will not follow the 7-dB-per-octave trend, but will lie somewhere above that line, then the 60-dB range objective can be considered adequate for most noise study purposes.

Having discussed the dynamic range relative to an overall sound pressure level (OASPL) in terms of "instantaneous" spectra, it is now necessary to define the total dynamic range required of the system in terms of the expected variance of this overall level over extended flight path ranges, altitudes and various helicopter types. A conservative estimate of the upper limit of dynamic range can be taken as 125 dBSPL, which is well within the capabilities of most microphone systems. However, the lower limit of range is a difficult criterion to specify for practical measurement systems. In theory, it is desirable that for subjective studies, the measurement capability extend below the threshold of hearing; in practice, this is attainable with specialized system components. However, such components (usually the microphone assembly) are highly directional and have a restricted upper frequency limit, as will be shown in Section 3.2. Further, the total dynamic range of, say, 10 dB to 125 dBSPL would exceed the signal-to-noise capability of the recording system at any singular gain setting of the recorder and preconditioning equipment, thereby necessitating the use of a gain adjustment procedure during a flight approach and flyby. To minimize the influence of such adjustments on subsequent analysis, the gain applied to each signal prior to recording could be either step-adjusted in fixed increments (of the order of 10 dB) or continuously automatically controlled according to the signal strength. In the latter case, it is essential that the variable gain be continuously recorded in such a manner that it may be easily retrieved and employed in the data-analysis tasks. Such procedures would allow optimum use of available measurement and recording equipment

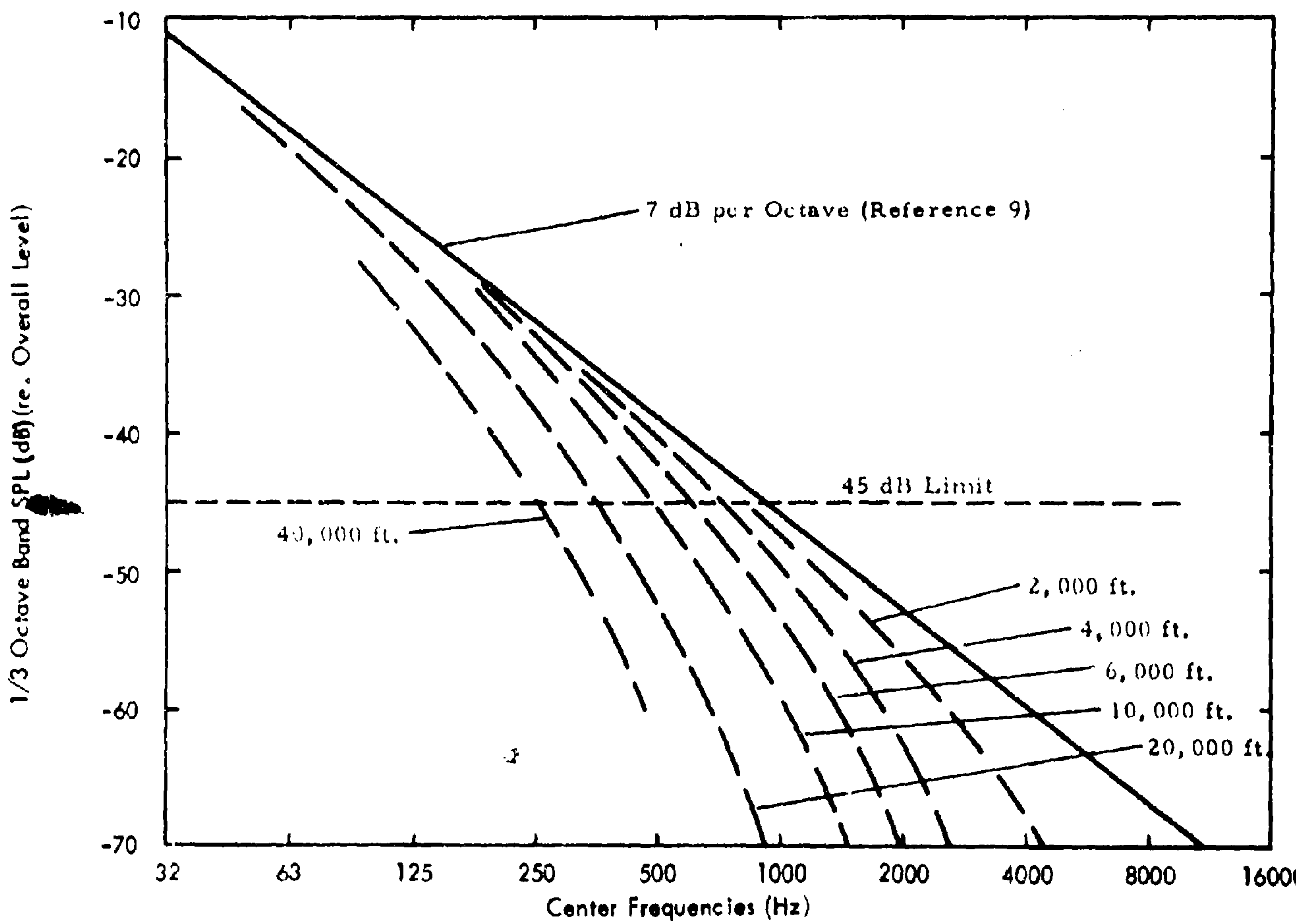

Figure 3. Effect of Atmospheric Attenuation on Spectral Roll-Off at Specific Distances from Source.

and would allow the practical total dynamic range to be determined only by the microphone capability.

In the preceding discussions the methods of frequency preemphasis and gain control will introduce nonlinearities into the recorded analog of the acoustic signal. By corresponding deemphasis and gain linearization or reproduction from the tape recorder, the final replayed signals should be in the required (linear-analog) form.

2.2.4 Harmonic and Phase Distortion

The total harmonic distortion is usually defined as a percentage of a pure tone level which will appear, through system nonlinearities, in the frequency range outside the tone frequency. When stated in dB units, a distortion of 1% will mean that the induced rms level of the pseudosignal is 40 dB below the input tone rms level (as given by $20 \log_{10} (.01)$). Taking the spectral envelopes of Figures 2 and 3 as typical of helicopter noise, and remembering that the noise is predominantly harmonic as shown in Figure 1, a total distortion limit of the order of 30 dB will ensure that the pseudosignal is at least 9 dB below the third harmonic of the primary signal. This 30-dB limit corresponds approximately to a 3% total harmonic distortion.

Phase distortion in a periodic signal will alter the basic shape of the signal, even when the harmonic content amplitudes are linearly retained. In effect, the rms value of the signal is not changed by phase distortion, but the crest factor (that is, the ratio of the maximum amplitude to the rms level) is modified. The influence of this effect on the subjective analysis of helicopter noise is not sufficiently understood to allow a clear definition of measurement requirements. However, based on the illustrative examples of phase shift effects contained in Reference 4, a tentative objective of retaining the phase linearity of the signal within $\pm 10^{\circ}$, over a frequency range encompassing the first ten harmonics of the fundamental blade passage component, can be stated. Alternatively, where such phase control cannot be obtained without compromising other linearities, a phase calibration should be conducted on the measurement system for future reference in interpretive studies of the data.

2.2.5 Transient Response

The basic pulsatile nature of helicopter noise, together with the intermittent (transient) phenomenon of blade slap, requires that the acquisition system be capable of admitting and recording signals with high rise-rates and with high crest factors. In system specifications, the

former capability is related to the frequency range of the system response, and is further defined as a percentage overshoot at some specified transient condition. To conform with this terminology, the requirements on helicopter noise measurement can be stated as: less than 12% overshoot (1 dB) for a rise time of 20 microseconds between the 10% and 90% points of the transient (approximately 1 dB per microsecond rise rate). It is essential that the maximum amplitude of the signal to the recording equipment does not exceed the specified deviation limit for the required distortion control. While this is ensured for most types of noise recording by nominating a maximum rms input level based on expected crest factors, helicopter noise does not allow such simplified procedures due to the random occurrence of "slap" conditions. Consequently, the input level must be based on "on-line" monitored information, appropriate to the helicopter type and flight condition, for each microphone signal.

2.2.6 Directivity

For all noise-generating mechanisms other than an ideal simple source, the radiated sound has directional characteristics that affect the spatial distribution of the sound pressure in the far field. In helicopter noise, this distribution is extremely complex due to the variety of mechanisms involved and the asymmetrical characteristics of the predominant generators (the rotors) in forward flight. However, a definition of such directional properties is essential to an interpretative study of detectability or source mechanisms, and must therefore be resolved in the noise measurement program.

The procedures used to obtain directivity data are encumbered by two basic problems. For a moving source, the distance and azimuth angle between the source and a stationary microphone are varying continuously. Hence, the sound pressure recording is a nonstationary process requiring time-increment analysis over small sample periods. To adequately cover the entire polar region within a reasonable distance of the helicopter flight path would require a large number of microphones distributed over a wide field area. However, such a procedure is cumbersome due to the long cable lengths necessary for input of all microphone signals to a single recorder or the alternative requirement for a number of time-synchronized recorder systems. As a compromise, a microphone array of practical separation distances is usually chosen. For the present program in which both hover and flyover noise data are to be acquired, two arrangements of microphone locations are desirable. For the flyover data, the array should consist of at least five microphone units distributed along a line normal to the flight path ground trace. The center unit should be located immediately under the

flight path and the others should be distributed on either side of this central unit. With this arrangement, the helicopter flights should be conducted at various altitudes to allow an analysis of the directivity characteristics about the rotor disc plane. It is important that the microphones do not induce directionality errors during a flyover, and this can be accomplished by the proper choice of units and by mounting the microphones in a suitable orientation to the ground plane.

For the hover data acquisition, the microphone arrangement should consist of at least five microphones located at fixed radii from a ground-marker hover point. This arrangement should allow a resolution of directivity characteristics at 15-degree increments around the helicopter at a (ground plane) radius of at least 1,000 feet from the hover marker point. Additional data at some larger radius are also desirable but will obviously depend on the geography of the measurement site. Again, the microphone directionality characteristics must be eliminated from the acquisition process. The actual arrays employed in the measurement program are defined in Section 4.2.

2.2.7 Other Measurement and Storage Requirements

In the analysis and interpretation of sound history data, it is essential that some means of identifying the vehicle's position relative to sound measurement point be available on the noise record tape or on a separate, time-coded record. Among the methods commonly employed for this purpose are: precision radar tracking, photography, pulse superposition on the sound record at specific points on the flight path, and simple speech-track monitoring. Obviously, each of these methods incurs different magnitudes of error, and their application is usually dependent on the analysis objectives or the availability of suitable equipment. The use of radar tracking is recommended in all future programs of noise measurement, and should be supplemented by one other method by which approximate information on the helicopter's flight position can be immediately stored on magnetic tape with the noise data.

The use of a standard time code on the recording tape serves at least two purposes; it provides a direct time correlation between independent data recording systems, and it facilitates data processing by means of time-code translation/tape search equipment. The following recommendations on time code format are based on the accuracy desired of the time correlations and the ease of interpretation:

- The time code should be of pulse amplitude modulated format on a 1000 Hz sine wave carrier.

- The code time frame should be 1 second, allowing a minimum resolution of 100 milliseconds.

Calibration and meteorological data are obvious necessities in a noise measurement program. A discussion of calibration procedures is included in Section 4. Meteorological data should be obtained at 1-hour intervals during each flight schedule and should comprise the following conditions at the measurement site:

- Local standard time
- Dry bulb temperature
- Relative humidity
- Station barometric pressure
- Altimeter setting (pressure)
- Wind direction and velocity

The final storage format of tape-recorded noise data in a data-bank system depends almost entirely on the type of reproduction equipment most commonly available to the users. A further consideration is whether extensive cross-correlation analysis, between microphone signals, will be conducted on the data. In cases where the noise data from the microphone stations are transmitted to a single recording station and simultaneously recorded on multichannel tape, the only requirement is that a standard recording technique be employed which will define tape transport speed, tape track separation, etc. This standardization is fortunately available in magnetic tape recording systems complying with the well-known IRIG specifications (Reference 10). Further discussion of these standards is presented in Section 3.2 together with recommended assignments of channel content.

In cases where separate recording stations are used for different microphone signals, the use of a time-code to synchronize the noise time histories is essential. For final data-bank storage of these records, it is recommended that the separate noise histories be synchronized and transposed to a single multichannel tape.

2.3 ANALYSIS REQUIREMENTS

From an idealistic view, it is desirable to analyze the recorded data with as much resolution as possible. The main requirement for most research and development purposes is to define the detailed frequency distribution of acoustic energy. High resolution implies narrow bandwidth analysis, and in general the aim is to reduce the bandwidth to a minimum.

The choice of analysis bandwidth is dictated by conflicting requirements of resolution, accuracy, and speed. The trade-offs between these factors for either harmonic or random noise are fairly well understood, but the presence of both in helicopter noise imposed double constraints on the selection. The spectrum analysis is performed in three stages: the signal is first filtered by the appropriate bandwidth Δf, is squared, and is averaged over a time T. For random noise, where the power spectral density w(f) is also required, the result is also divided by the bandwidth. Mathematically, this process can be written as

$$\overline{p}\;(f, \Delta f) = \frac{1}{T}\int_0^T p(t,\ f,\ \Delta f)\ dt$$

$$\text{and } w(f) = \frac{p\ \ (f,\ \Delta f)}{\Delta f}$$

where $p(t,\ f, \Delta f)$ is the instantaneous value, at time t, of the square of the signal level after filtering by bandwidth Δf, centered on frequency f. $\overline{p}(f,\ \Delta f)$ is the mean square value of the signal, within bandwidth Δf, centered on frequency f, averaged over time T.

Dealing first with stationary random noise, that is random noise whose statistical properties and average sound pressure level (SPL) do not vary over long periods of time, the main difficulty is associated with the fact that the short-term SPL is not constant, so that the output of a sound level meter (which actually measures a running average of $\overline{p}$) fluctuates in level. The amount of the fluctuation increases as the product of bandwidth and averaging time decreases. At any instant, the meter is more likely to underestimate the true value than vice versa; but to obtain 80% confidence limits of $\pm$ 1 dB, the product of Δf x T must be greater than about 35.

For harmonic noise, on the other hand, the requirements are not so stringent. The error in the measured SPL of a filtered discrete frequency component will be less than $\pm$ 1 dB provided the averaging time is greater than about one period. For example, for the lowest harmonic in helicopter noise, namely, the main rotor blade passage frequency, is seldom less than 10 Hz and an averaging time of 100 msec will suffice. Assuming that a 3 Hz bandwidth is sufficient to resolve individual harmonics, the corresponding averaging time required to evaluate the random components in the same frequency band is about 12 seconds.

A convenient solution to this problem is to use narrow bandwidths at low frequencies where harmonic components dominate and wider bandwidths at high frequencies where random noise energy greatly exceeds any periodic components. Analog filter systems with variable bandwidths are usually designed as constant percentage bandwidth analyzers and, as the name implies, have bandwidths which are proportional to the band center frequency.

Unfortunately, this can lead to an averaging problem, since if the bandwidth is sufficiently wide to admit a group of harmonic components, a high crest factor signal may be passed. Filtered harmonic noise has the form of a highly modulated sinusoidal signal, and for 1/3 octave band filters which are perhaps the most commonly used constant percentage devices for aircraft noise purposes, crest factors as high as 9 dB are possible. Such signals cause problems for analog rms detectors that are normally limited to signals with small crest factors. The result can be very large errors, and for safety, a substantially greater averaging time (by a factor of perhaps 3 to 5) should be used. This also applies to the linear (unfiltered) signal. Probably the safest way to avoid this problem is to use a digital averaging system that actually performs a numerical integration.

The problems of helicopter noise analysis are reviewed in Reference 4, and the findings of that report can be summarized as follows:

1. For practically all applications, helicopter sound recordings must be analyzed to define the frequency distribution of acoustic energy. An appropriate procedure for spectral analysis must be selected to optimize the requirements of resolution, accuracy, and speed. For either periodic or random noise, the requirements are well defined. The need to consider both in the case of helicopter noise imposes twofold constraints on the selection.

2. For harmonic noise, a narrow filter bandwidth is required, considerably less than the fundamental frequency of interest (which is equal to the interharmonic spacing). The averaging time of the rms detection should be greater than 1.33 periods of the component under analysis for an accuracy of $\pm$ 0.5 dB, or greater than 0.8 periods for an error of less than $\pm$ 1 dB.

3. For random noise, the error increases as the product of bandwidth and averaging time decreases. For an accuracy of $\pm$ 1 dB this product should exceed 40, and for $\pm$ 0.5 dB accuracy, products greater than 200 are necessary. If the modulation

amplitudes are required, the averaging times must be very small (typically 20 msec) so that they can only be detected by very coarse filters, unless provision is made to average a series of modulation cycles.

4. For long-duration hover recordings, the main constraint upon the analysis is the physical time involved. For example, detailed narrow band analysis can take several hours. For flyby recordings, the signal is nonstationary, and an additional requirement is that the spectral characteristics should not change significantly during the averaging time. The selection of an averaging time must be based upon the flight configuration under study, but this consideration generally eliminates the ability to perform a narrow band analysis at the higher frequencies. Harmonic components, however, can be extracted with reasonable accuracy using high-speed analysis equipment.

5. For general purpose analysis of flight data, 1/3 octave analysis is recommended since it provides a reasonable compromise between resolution, accuracy, and speed; it represents an adequate analog of the hearing mechanism; and it is widely available in commercial analysis systems.

6. Real-time analyzers are very useful for high speed, large volume acoustic data reduction and are particularly appropriate for flyby data analysis. However, care is required to meet the accuracy requirements existing for all spectrum analysis, particularly with regard to averaging time.

7. When interpreting filtered data, it is easy to confuse modulated random noise with the waveform of a group of harmonics, since both exhibit a modulation envelope with a period equal to the blade passage interval. The safest way to discriminate between them is to perform a narrow band analysis of the filter output.

8. The accurate measurement of pulsatile sound pressure levels with high crest factors requires an elaborate rms detection circuit. Averaging times should be several times greater than modulated periods. Failure to meet this requirement can lead to severe errors in the measurement of highly modulated signals.

3.0 DATA ACQUISITION SYSTEMS

3.1 GENERAL DESCRIPTION

A remote field noise data acquisition system can be regarded as an assembly of four primary subsystems:

- A field microphone system
- A signal conditioning console
- A data storage unit (tape recorder)
- A signal monitoring system

A typical assembly of these is illustrated in Figure 4. In addition, the inclusion of a time code generator, a voice narration microphone, and aircraft tracking facilities is essential to the noise measurement test program, but do not directly affect the acoustic signal processing. Calibration facilities are also necessary and can be catagorized as laboratory and field systems. These are discussed separately in Section 4.

Each of the subsystems listed above has limitations in its signal processing capabilities that will induce constraints on the overall system. For example, the frequency response capabilities of a properly selected tape recorder are well in excess of requirements, but a severe limitation in dynamic range is associated with this unit. In contrast, the dynamic range of microphone systems far exceeds that of the recorder; but, as will be shown in the following sections, the frequency response range of microphones can be a problematic restriction. The objectives of the following sections are therefore to review the typical characteristics of equipment items which are commonly used in these subsystems, and to make recommendations on overall system designs that will be best suited to the measurement of helicopter noise for data-bank storage.

3.2 FIELD MICROPHONE SYSTEMS

The first element in a noise measurement system is obviously the transducer, or microphone, which responds to the acoustic pressure field and, in conjunction with an appropriate preamplifier, generates an electrical analog of the pressure field. Two types of microphone units are commonly employed in acoustic precision measurements; the condenser type which relies on the vibrational response of a thin metallic diaphragm to vary the electrical voltage across a capacitive gap between the diaphragm and a polarized electrode, and the

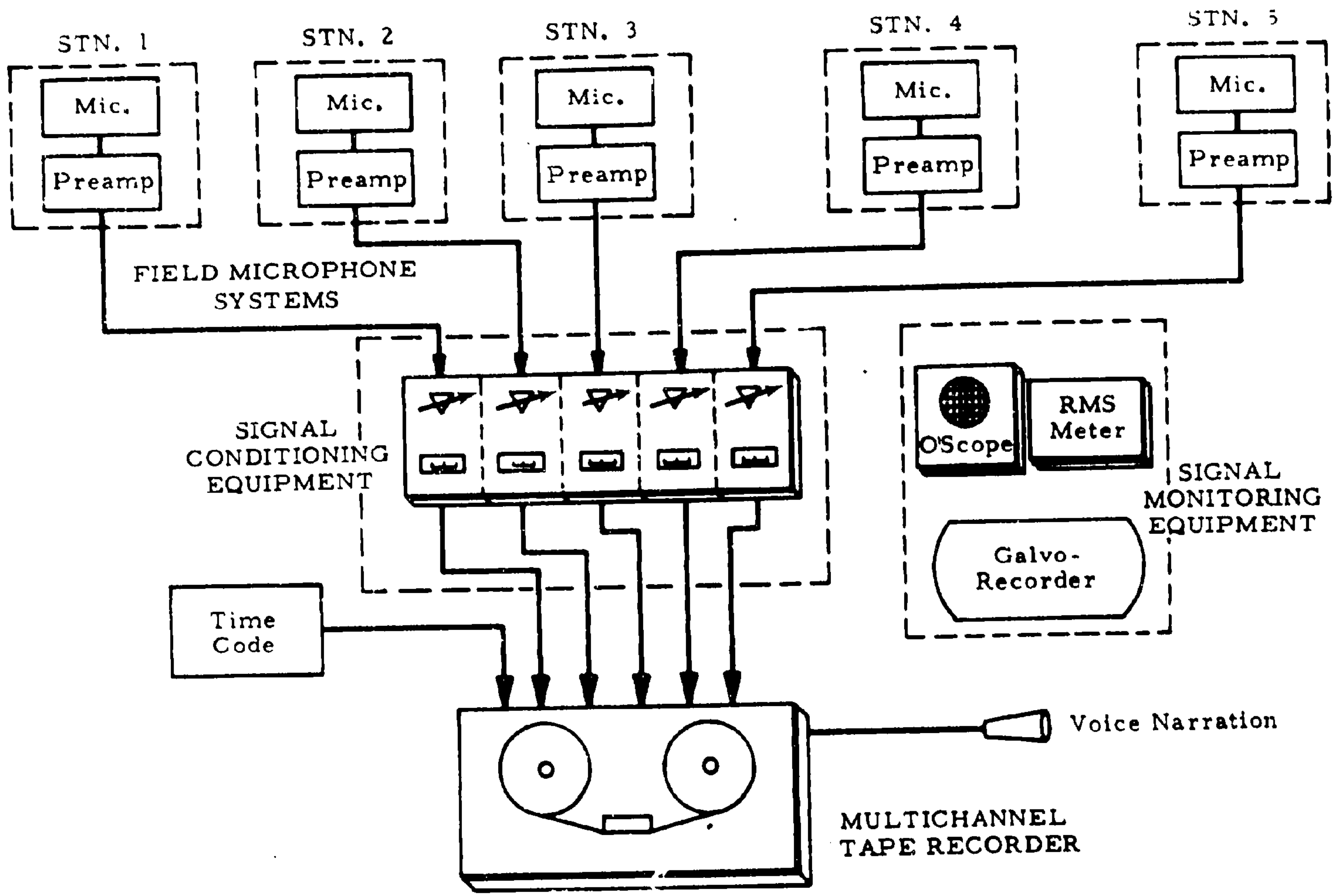

Figure 4. Major Components of a Rem-te-Field Noise Measurement System.

piezoelectric (or ceramic) type which relies on the dynamic strain response of a piezoelectric material to the incident sound pressure. Further catagorization of these types is denoted by their directionality characteristics, as pressure, free-field or random incidence types. In each case, a preamplifier is a necessary item at the microphone station, and this requires a power supply, which may be a remote unit or may be installed at the signal conditioning terminal with power transmitted to the microphone station via cables. The signal from the microphone preamplifier is usually transmitted to the signal conditioning equipment by means of well-insulated cables, which may incorporate cable amplifier units at certain points along their length when long distances are to be covered.

The above items of equipment, excluding the signal conditioning units, can be regarded as components of a "field microphone system". Additional components of the system are a microphone support stand (tripod) and a windscreen.

Prior to discussing the measurement capabilities of microphones in detail, it is advisable to consider the implications of the directivity characteristics of the three subcatagories. In general, the directivity of a microphone is the variance of its response to sound waves impinging at different angles to the microphone axis, with respect to a true measurement of the sound pressure amplitude. As is shown in Figure 5, this variance from a linear response is usually only apparent at frequencies above 1000 Hz and is attributable to phase cancellation of the impinging wave on the transducing element surface. To compensate for such effects, the three types of units have been designed for particular applications.

The free-field unit is suited to situations where the sound field is predominantly plane wave progressive and the microphone can always be directed toward the noise source. Its frequency response is linear up to frequencies in excess of 15 kHz for frontal incidence sound waves, but exhibits a sharp decay for other incidences, particularly grazing incidence. This roll-off characteristic of the free-field type occurs at relatively low frequencies compared with other types of equivalent sensitivity*.

*The term "sensitivity" is the response rate of the microphone and is usually specified in millibars per microvolt.

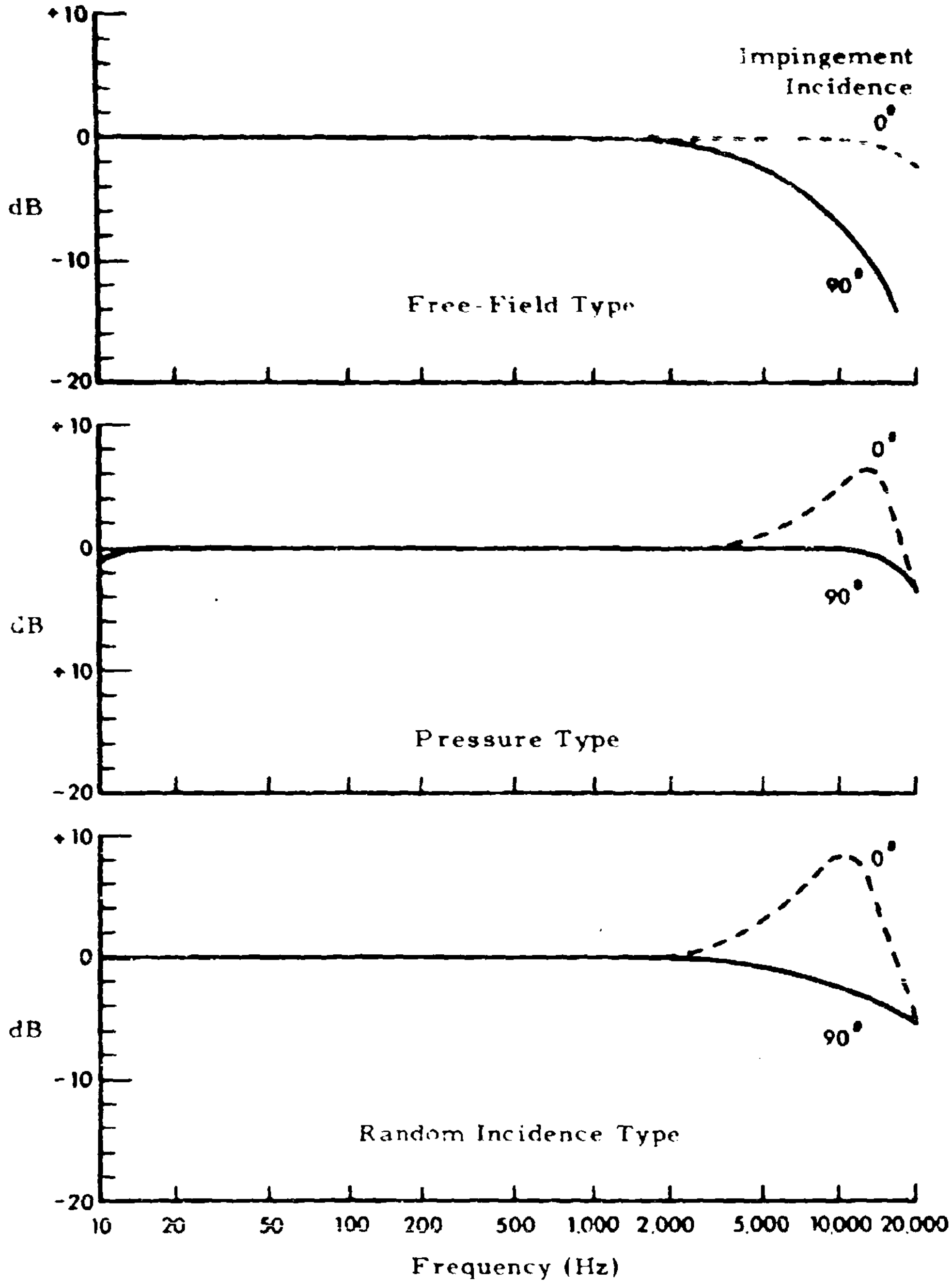

Figure 5. Microphone Response Characteristics.

The pressure microphone is, as its name implied, best suited to the measurement of "pressure" fields in which the sound pressure and particle velocity are completely out of phase and spatially uniform, and consequently do not induce over-response in the critical frequency region. However, this type of microphone will over-respond to frontal progressive waves. Its greatest advantage is that it provides a more extensive linear frequency response range for grazing incidence progressive waves as shown in Figure 5.

The random incidence response microphone is a result of deliberate efforts to design a unit which will respond equally to sound waves impinging simultaneously from all directions. This is usually achieved by the application of an incidence correction shield to a pressure-type transducer. Its high frequency response at any single impingement angle is usually inferior to that of a free-field or pressure-type unit used at the proper orientation.

For aircraft flyover noise measurements it is obvious that, if incidence corrections during the measurement period are to be avoided, each microphone unit should be oriented such that the entire flight path is in the grazing incidence plane of the microphone. Consequently, a pressure type unit is best suited to this purpose when the linear response range is required to extend the high frequencies.

It is an unfortunate circumstance in microphone characteristics that the linear frequency range of a microphone decreases with increasing diameter of the unit while the sensitivity increases with increased size. For the present case of helicopter noise measurement, where data is desired over a large range of signal levels including, in particular, very low levels near the threshold of hearing, a high microphone sensitivity is required to achieve such requirements. This is due to the fact that the inherent noise in the microphone assembly determines the lower limit of the measurable sound level range. A high sensitivity will cause the electrical signal level, corresponding to a low sound level, to be discernable above the inherent noise floor. Table II, which contains the frequency and dynamic range limits of typical microphone systems, illustrates the necessity for compromise between the ideal requirements on these characteristics. A practical approach to the problem lies in the use of both free-field and pressure type microphones. For relatively short distance flyover noise measurements, it is considered that the frequency range and directivity characteristics of the microphone take precedence. Therefore, the use of 1/2-inch-diameter pressure type units is recommended for a spatial array of microphones. For large distance approach noise measurements, the use of a single 1-inch-diameter free-field type microphone, oriented with its axis

TABLE II. MICROPHONE LINEAR RANGE SPECIFICATIONS

Type	Model	Diameter (in.)	Dynamic Range (dB) +	Frequency Response Normal Incidence	Range (Hz) Grazing Incidence
Free Field	B&K4145	1.0	10-146	2-18k (± 2dB)	2-1.5k (± 2dB)
	B&K4117*	1.0	N-140	3-10k (± 3dB)	
	HP 15109B	1.0		20-16k	20-3 k (± 2dB)
	HP 15119A	0.5		20-25k	20-6 k (± 2dB)
	B&K4148	0.5	28-140	4-16k (± 2dB)	20-6 k (± 2dB)
	B&K4133	0.5	32-160	5-40k (± 2dB)	
Press	B&K4146	1.0	10-146		0.1-7 k (± 2dB)
	B&K4144	1.0	10-146		2-7 k (± 2dB)
	B&K4134	0.5	32-160		5-20k (± 2dB)
Random	GR 1560P*	1.0	N-135		5-10k (± 2dB)

*Piezoelectric Type   N - Lower Limit Not Specified   + Range From Noise Level to 4% Distortion

along the line of approach, is recommended. The data obtained by this microphone should be considered accurate for large approach distances only.

In each of the above applications, the microphone should be used with an appropriate FET preamplifier to minimize system noise and to obtain the lo[illegible]equency capabilities. The upper frequency capabilities of the system are further influenced by the connecting cable between the preamplifier and the conditioning equipment. This can be alleviated by using a low capacitance cable, such that the total capacitive loading is less than 26500 pF for a 15 kHz cutoff (i.e., less than 17.6 pF per foot length for a 1500-foot cable). Another method of eliminating this problem is to employ cable amplifiers at various positions along the cable length.

Phase distortion within the microphone and carrier system has not been specifically defined as yet due to the construction of cartridge and preamplifier units. It is therefore concluded that the phase distortion in each channel of the entire system (including signal conditioning and recorder units) should be defined over the desired frequency range by calibration procedures. An electrical calibration should be conducted by square-wave input at the preamplifier, recorded on the appropriate tape-deck channels. Subsequent Fourier analysis of the recorded signals will provide a direct comparison of input and acquired-data phase relationships.

3.3 TAPE RECORDING SYSTEMS

Although conditioning and monitoring of the data signal is conducted prior to tape recording, the primary purpose of this process is to ensure that the input signal to the recorder is within the specified limits for proper functioning of the recorder. Consequently, the limitations of tape recording systems are now reviewed, and the methods of conditioning and monitoring are discussed in Section 3.4 with respect to these limitations.

To ensure compatibility of tape-transport speeds, headstack configurations, bandwidths, etc., in the acquisition and later reproduce/analysis stages of data collection, the tape recorder systems employed for permanent data storage should conform to IRIG specifications (Reference 10). For helicopter noise data, in which very low frequencies are important, it is necessary to employ a recorder with frequency modulation (FM) electronics, which allows acquisition of signal components down to DC levels. Further restrictions on the choice of system are

based on the IRIG standards for FM recording. To achieve a $\pm$ 1 dB response over a frequency range of DC to 20 kHz, it is recommended that IRIG Intermediate Band recording be used at a tape transport speed of 60 ips. A further standardization of helicopter noise data storage can be achieved by the use of a 14-channel recorder with the following track assignments:

Channel 1 is allocated to a Standard Time Code.

Channels 2, 3, and 4 are allocated to vehicle tracking data, if available in a suitable input form, or to other information relating to the helicopter's flight location during the signal history.

Channels 5 to 12 are allocated to noise data.

Channels 13 and 14 are reserved for voice-narration of identification data, operating conditions and other data-log information.

A review of commercially available FM recording systems conforming with the above requirements indicates that the only serious limitation, in terms of dynamic capabilities, is that of signal-to-noise ratio. This limitation is more severe in FM systems than in Direct Record units, but the latter do not allow low frequency acquisitions and are therefore not considered in the present review.

A typical value of the signal-to-noise ratio (S/N) of IRIG Intermediate Band systems is 45 dB. For a nominal input level of 1 volt rms (which is adjustable within the recorder electronics), the maximum permissible amplitude to be recorded within the specified distortion limits is 1.4 volts peak. This is called the "40% deviation limit". The problem incurred by the 45 dB S/N ratio can be explained with reference to this peak limit and the crest-factor characteristics of helicopter noise. The total signal waveform of helicopter noise has a crest factor of the order of 16 dB. (This value was found to be typical during the field tests described in Section 4.) If the input signal to the tape recorder is conditioned such that its peak level is 1.4 volts, the overall rms level of the signal would be approximately 200 millivolts, which is 16 dB below the 40% deviation limit. Thus the available dynamic range, in terms of sound pressures which are evaluated in rms levels, is reduced to the order of 29 dB. Reference to the frequency spectra of Figures 1 through 3 illustrates the inadequacy of this range for acquisition of the high frequency content of the signal. Consequently, high frequency preemphasis of the signal, prior to recording, is necessary.

To fully utilize this limited dynamic range, it is essential that the maximum peak amplitude of the signal history is as close as possible to the 40% deviation limit without exceeding it. This can only be accomplished by detailed monitoring of the signal content to determine appropriate gain or attenuation settings of the conditioning equipment.

3.4 SIGNAL CONDITIONING AND MONITORING SYSTEMS

The signal level transmitted from the microphone to the recording terminal, via cables and cable amplifiers, is usually determined only by the (fixed) sensitivity of the microphone system. In order to adjust this signal level such that the input to the tape recorder is within the specified limits of that unit, signal conditioning and monitoring equipment is necessary. The former of these can be catagorized as voltage-amplifier and preemphasis units. Monitoring can be conducted by means of rms meters, peak level detectors, oscilloscopes, oscillograph chart recorders, etc. In some equipment items, such as sound level meters, both capabilities of signal level monitoring and output level control are incorporated.

Considering first the voltage gain/attenuation stage of the conditioning, the most important objectives are to adjust the signal level to the required recording level without inducing any nonlinearity or distortion in the basic signal waveform, and to identify exactly the modified sensitivity of the recorded signal such that the input and reproduced voltage levels can be accurately related to the measured sound pressure levels. The former objective is met by selection of an amplifier system that has frequency response, dynamic range and distortion characteristics compatible with the signal acquisition requirements. For helicopter noise data the frequency range requirements can be met by the use of a DC amplifier or a wide-band voltage amplifier with linear response from 2 Hz to 20 kHz. Such units usually have amplitude range and transient response capabilities in excess of those of the recorder unit, and should be checked at the system-design stage. The increments of level adjustment available in voltage amplifiers varies with model type. Models designed specifically for acoustic signal applications usually have 10 dB stepped increment adjustments of gain and attenuation over a total range of $\pm$ 40 dB (or more) relative to the input level. Due to the problem of optimizing the use of the recorder range, a stepped increment adjustment capability of 5 dB is most desirable for helicopter noise processing. This can be obtained from the instrumentation manufacturers if specifically requested. The most common method of identifying the recording sensitivity is to set a specific rms voltage recording level for known acoustical calibration level input at the microphone, and to note the

change in gain/attenuation setting employed during the helicopter noise recording test. For example, a calibration equivalence of 114 dBSPL for 1 volt rms will be changed to 84 dB at the same rms voltage if the system gain setting is altered by +30 dB (that is, 3 increments of +10 dB). This method is satisfactory but should be periodically supplemented by an absolute sensitivity check due to the possibility of variances induced by degradation of batteries and polarization voltage, or by effects of meteorological conditions.

Preemphasis in signal conditioning is essential to helicopter noise acquisition when the sources of higher frequency noise are to be studied. Basically, preemphasis involves a frequency dependent weighting of the gain applied to a signal prior to recording. This capability is currently being introduced to acoustic measurement equipment, but requires that compatible deemphasis equipment be available at the reproduce/ analysis stage, or the interpretation of analyzed data must take the weighting-shape into consideration. An alternative method is to record, on separate recorder channels, the basic (unweighted) signal and a high pass filtered content of the signal. The filtered content can then be amplified to a recordable level. This method is inefficient due to the requirement of two data channels per microphone signal, but should be used if preemphasis systems are not available. Based on the spectrum slope shown in Figure 3, a suitable cutoff frequency for high pass filtered preemphasis in helicopter noise acquisition is about 250 Hz. Thus the overall rms level of the filtered component will be about 15 dB to 20 dB lower than that of the basic (unfiltered) signal, and should be separately amplified to an optimum recording level. It is important that the sound pressure level equivalence of the preemphasized signal be identified separately.

The nature of helicopter noise creates additional problems in data acquisition due to occurrence of high level transients on the basic pulsatile signal. As these transients are of considerable interest in helicopter noise studies, care must be taken to include them in the data record. It is therefore necessary to include at least two types of signal monitoring -- that of rms level, and one other method by which the maximum signal amplitude can be noted. Root mean square monitoring meters are incorporated in most signal conditioning systems. Monitoring of the maximum peak amplitudes in a signal history is also available in some sound level meter systems which also provide output level control, but oscilloscope or oscillograph recorders are more commonly used. The latter method allows simultaneous multichannel monitoring and is preferred for the present case where separate signal conditioning adjustments are necessary on each data acquisition channel. By setting reference (peak) levels on each oscillograph channel, the complete

history of each signal to be input to the tape recorder can be permanently stored on chart-paper for examination of overloading conditions and appropriate readjustment of the gain settings. In hover flight cases, these monitoring and adjustment processes can be conducted immediately prior to tape recording the noise, while the helicopter is maintaining position. In flyover cases, however, manual adjustment of the gain settings cannot be properly conducted during the flight approach and pass. The most satisfactory practical approach to this problem is to conduct a preliminary, noise monitoring flight at the required flight condition, make the necessary gain adjustments during or immediately after this flight, and then conduct the final noise data acquisition flight test. While it is known that differences in helicopter noise occur under (attempted) repeated flight conditions, the test procedure described above has been found to provide a best approach. By also monitoring the data during the noise acquisition flights, any cases in which overload conditions are encountered can be identified immediately and repeated.

The subject of gain-adjustment (during a flight) has not been satisfactorily resolved during this review. Various systems of automatic gain control have been considered but impose severe restrictions on the analysis procedures, or require additional data tracks for gain-level recordings. Further detailed study of automated signal conditioning for helicopter noise recording is recommended.

4.0 TEST PROGRAM AND PROCEDURES

4.1 GENERAL DESCRIPTION

The noise measurement program was conducted at Camp Pickett, Virginia, during the period from September 23 to November 9, 1970. Five helicopter types were examined:

UH-1B
OH-6A
AH-1G
CH-47B
CH-54A

Noise data were obtained for each of these types at hover and flyover conditions as listed in Table III. A measurement array comprising five microphone systems was used in the program; the spatial distribution of these systems at the field site differed for hover and flyover tests. An additional free-field microphone with high sensitivity was used in some flyover test cases. Radar tracking facilities were not available during the program and a simplified procedure for time-relating the helicopters' flight path position and the noise records was used.

Flight cabin instrumentation data were logged during each noise measurement flight. Meteorological and ambient noise data were obtained at suitable time intervals during each day of the test program.

4.2 FIELD ARRANGEMENT OF MICROPHONES

Two arrangements of microphone locations were marked out at the Camp Pickett site, as illustrated in Figure 6. These positions were located by the use of measurement chains and a surveying transit. The hover array was located relative to a hover point ground marker near the intersection of runways 21 and 26 and comprised three microphones at a radius of 2000 feet and two microphones at a radius of 3000 feet from this marker. The numeric identification of these units is indicated in Figure 6(a). The reference azimuth adopted for the hover tests was along the line parallel to runway 21, through the hover point ground marker. The hover array allowed noise measurements at 15-degree increments at a 2000-foot radius, and at 22.5-degree increments at a 3000-foot radius.

TABLE III. SUMMARY OF NOISE MEASUREMENT CONDITIONS				
Helicopter Type	Flight Conditions			
	Altitude (ft)		Velocity (kts)	
UH-1B	200	-	60	100
	500	H	60	100
	1000	H	60	100
OH-6A	200	-	60	100
	500	-	60	100
	1000	H	60	100
AH-1G	200	-	70	150
	500	H	70	150
	1000	-	70	150
CH-47B	200	-	60	100
	500	H	60	100
	1000	H	60	100
CH-54A	200	-	60	100
	500	H	60	100
	1000	-	-	-

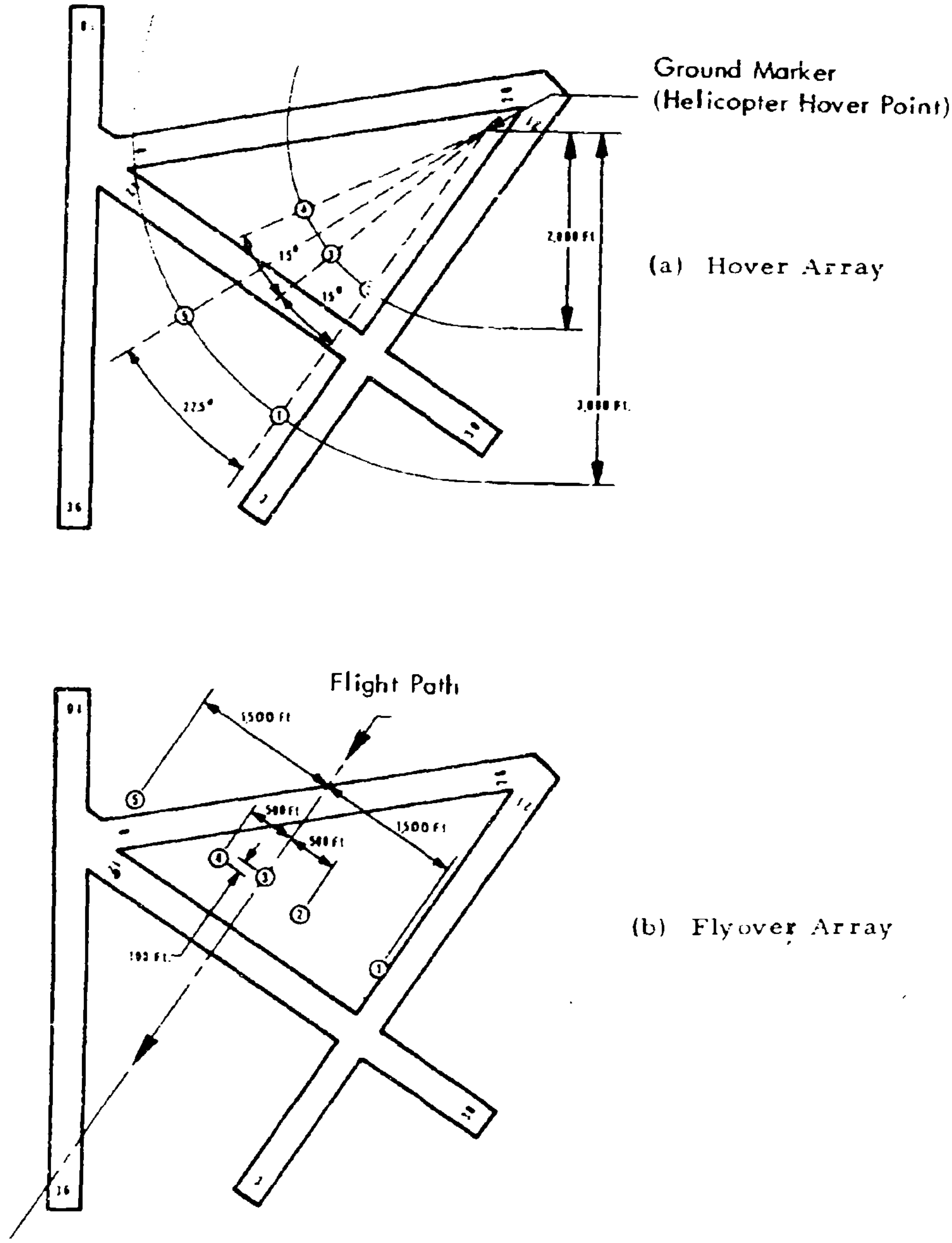

Figure 6. Field Microphone Arrays for Helicopter Noise Measurement.

The microphone array for the flyover program consisted of four microphones located along a line normal to the flight path ground trace, and a center unit displaced from this line by a distance of 100 feet. As shown in Figure 6(b), the outer units were at a distance of 1500 feet from the center marker and the inner units were displaced by 500 feet from this marker. Signal cables connected each of the microphones to the field terminal equipment which was contained in a van located about 150 feet from the center microphone.

4.3 INSTRUMENTATION

A schematic illustration of the instrumentation used in the measurement program is presented in Figure 7. A complete listing is included in Table IV. The field microphone systems and signal conditioning equipment were supplied as Government-furnished equipment by NASA Langley Research Center for this program. The noise signals from microphone nos. 1 to 5 were input via the conditioning units to channels 5 to 9 respectively of a 14-channel FM tape recorder. Branch signal lines from microphone nos. 4 and 5 were input to a high-pass filter of 250 Hz cutoff. The filtered signals were then suitably amplified prior to input to channels 10 and 11, respectively, of the tape recorder. Signal monitoring was conducted by means of the sound level meters, an rms voltmeter, an oscilloscope and an oscillograph recorder. The latter measurement system was then assembled (including cables) and end-to-end check-out and calibration were conducted by both acoustical input and insert voltage methods. The signal input at each microphone was recorded on the allocated channel of a calibration magnetic tape. These signals included a constant amplitude, swept frequency insert voltage over the range 2 Hz to 20 kHz, and square wave signals of 10 Hz and 50 Hz frequency. The acoustic input comprised 114 dBSPL signals at 125, 250, 500, 1000 and 2000 Hz respectively.

4.4 TEST PROCEDURES

4.4.1 Field Calibration

Field calibration was conducted by means of Sound Level Calibrators, providing an acoustical input of 114 dBSPL of frequencies at 2000, 1000, 500, 250 and 125 Hz respectively to each microphone. The signal level input to the tape recorder was adjusted, for each channel, to be 1 volt rms at the 1000 Hz frequency. The calibration tones were then recorded on the data tracks allocated to each microphone, preceding the helicopter noise records. The settings of all conditioning amplifiers

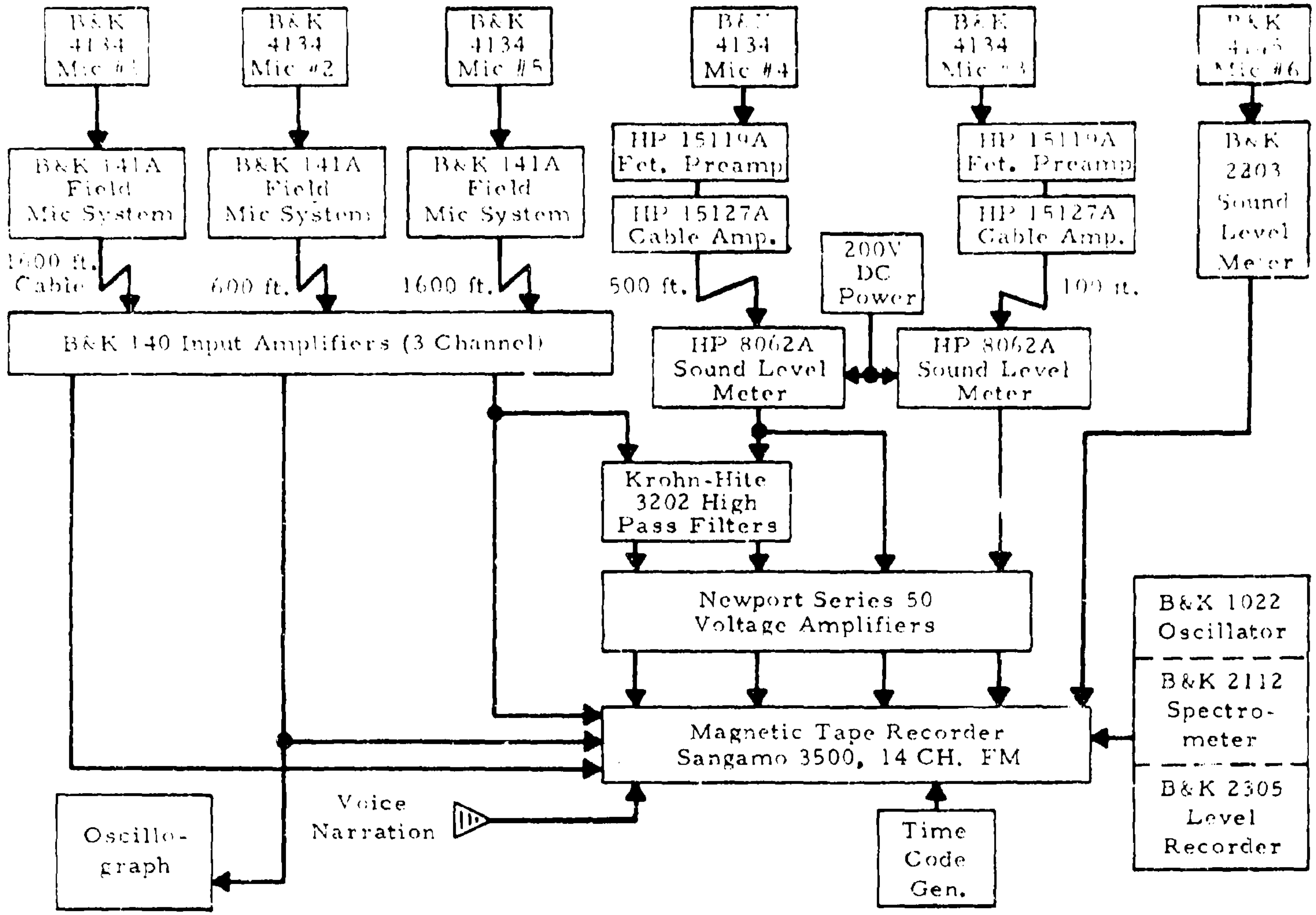

Figure 7. Schematic of Noise Measurement Instrumentation.

TABLE IV. LISTINGS OF EQUIPMENT ITEMS FOR HELICOPTER NOISE MEASUREMENTS

6	Tripod/Stand
5	B&K 4134 Microphone Cartridge
1	B&K 4145 Microphone Cartridge
3	B&K 141A Field Microphone System
2	HP 15119A Fet Preamplifier
2	HP 15127A Cable Amplifier
1	B&K 140-3AM Input Amplifier Set
2	HP 8062A Sound Level Meter
1	Krohn-Hite High Pass Filter (2 channels)
4	Elec. Insts. A20B-2 Voltage Amplifiers
1	Sangamo 3500 14 channel FM Tape Recorder
1	B&K 1022 Oscillator
1	B&K 2112 Spectrometer
1	B&K 2305 Level Recorder
1	Astrodata 7190-105 Time Code Generator
1	B&K 2203 Portable Sound Level Meter
1	PS207 7 channel FM Tape Recorder
2	1600 foot Beldon 8451 Cable (or equivalent)
1	600 foot Beldon 8451 Cable (or equivalent)
1	500 foot Beldon 8403 Cable (or equivalent)
1	100 foot Beldon 8403 Cable (or equivalent)
12	Scotch (317) 870-1-2500-IR Instrumentation Magnetic Tape
5	CEC 219305 Tpr Instrumentation Magnetic Tape
2	Gr 1562-A Sound Level Calibrator
1	B&K Pistonphone 4220
1	Movie Camera & Tripod,
2	12 volt DC batteries (80 amp. hrs.)
4	12 volt DC batteries (220 amp. hrs.)
1	275 watt Terado Inverter
1	1000 watt Topaz Inverter
1	Tektronix 321A Oscilloscope
1	Simpson 260 VOM
2	Allied Transceiver (2 watt)
1	CEC 5-124 Oscillograph Recorder
1	Sky 1515 MWP Communication Transceiver

were logged and used as reference settings for the noise acquisition tests. Post-flight calibration checks were conducted on all system channels but were not recorded on the data tapes.

4.4.2 Ambient Noise and Meteorological Data Recording

Ambient noise data were recorded on the noise data tapes at approximately 2-hour intervals during each acquisition program.

Meteorological data pertaining to conditions at the measurement site were received from the FAA Flight Service Station for each hour of each noise acquisition period.

4.4.3 Hover Test Procedures

The microphones were located relative to a ground marker as shown in Figure 6(a). Each microphone was mounted at a height of approximately 4 feet above ground level, and was oriented with its axis horizontal and with its grazing incidence plane through the hover point. Each helicopter was required to hover directly over the ground marker at a specified altitude. The helicopter orientation at that position was first required to be parallel to runway 21, that is, with its forward axis in the direction of microphone nos. 1 and 2. Noise data was then acquired on the oscillograph recorder for all filtered and nonfiltered channels. The conditioning amplifiers were then adjusted by step (10 dB) increments until the maximum peak amplitude of each signal was just within the 1.4-volt recording limit. All amplifier settings were noted in the data log, and a 30-second recording of the helicopter noise was obtained on the magnetic tape.

This procedure was repeated for each of eight orientations of the helicopter relative to the ground reference. All data obtained at each altitude was recorded on a separate (2500-foot length) magnetic tape.

The hover noise data recorded corresponds to the noise signature of the helicopter at 15-degree azimuthal increments on a ground radius of 2000 feet from the hover point, and at 22.5-degree azimuthal increments on a (ground) radius of 3000 feet from the hover point.

4.4.4 Flyover Test Procedures

The microphone array was positioned as shown in Figure 6(b). Each microphone was mounted at a height of approximately 4 feet above ground level with its polar orientation set such that the intended flight path of the helicopter would be in the grazing incidence plane of the microphone.

Radar tracking facilities were not available during this measurement program, and an alternative method of recording the helicopter's position was employed. This method used ground markers positioned directly under the flight path, at approach distances of 10,000 feet, 2,000 feet and 1,000 feet from the center (reference) of the microphone array, and at down-path distances of 1,000 feet and 3,300 feet from the reference point as shown in Figure 8. During the noise recordings, the instant of flyover at each of the ground marker positions was communicated to the recording terminal and input as a 10-dB change in level of a 1000-Hz oscillator signal to channel 2 of the magnetic tape. This oscillator signal code is illustrated relative to the flight path positive in Figure 8.

For each specified altitude and velocity condition, the "data-recording" flight was preceded by at least one preliminary flight at identical conditions. During the preliminary flight, signal monitoring was conducted by means of the oscillograph recorder as described in Section 3.4. The conditioning amplifiers were then adjusted such that the maximum peak amplitude of each signal would not exceed the 1.4 volt limit, and these amplifier settings were noted in the data log.

In "data-recording" flights, noise data acquisition on the magnetic tape commenced when the helicopter was at an approach distance of approximately 12,000 feet from the microphone array reference position, and terminated when noise data had been acquired over a flight path of approximately 17,000 feet.

On-line monitoring of the signals during data recording was conducted by means of the oscillograph recorder and sound level meters.

This procedure was repeated for all flyover conditions.

All data recorded on each day of the measurement program was reviewed for signal limiting characteristics prior to program continuation.

4.5 REVIEW OF TEST PROGRAM

The following comments are based on the problems experienced during the program which should be anticipated and allowed for in future similar programs. Although some of these findings may appear trivial, their influence on a field test schedule and the quality of performance is notable.

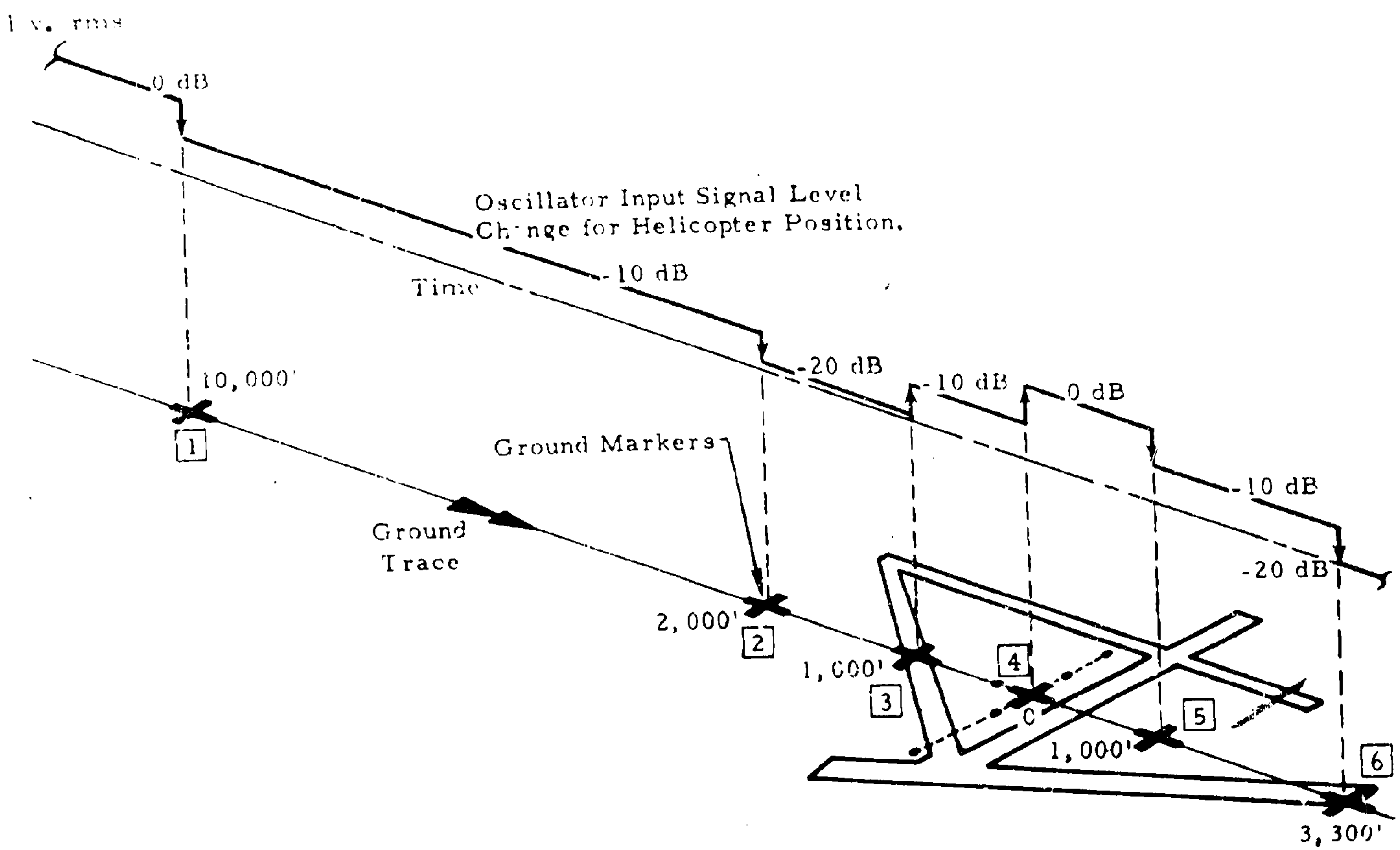

Figure 8. Illustration of Flight Path Marker Positions and Oscillator Code.

1. A noise measurement site must be carefully selected. For the present program, the Camp Pickett site was chosen because of its convenient location, its relative inactivity, and its reputed low ambient noise environment. A preliminary visit to the site appeared to confirm its suitability to the program, except for its lack of radar facilities. However, the actual program was regularly interrupted as a result of other military activities at the site and by unacceptable ambient noise levels due to a seasonal increase in local industrial operations.

2. The lack of permanent radar facilities at the site and the non-availability of substitute mobile tracking equipment precluded an adequate resolution of the helicopter flight path coordinates. The use of motion-photography was intended to supplement the ground-marker/oscillator code procedure but was discontinued due to the rescheduling of flyover tests to evening periods. It is recommended that radar tracking be available in future noise measurement programs on Army helicopters.

3. The reliability of power supply equipment was found to be unsatisfactory, although care was taken to make adequate allowance for transient loads, etc. Power failures occurred mainly when ambient (field) temperatures were over 80°F and could only be attributed to the high temperature conditions, as subsequent laboratory inspections indicated no system faults.

   Four solid-state inverters were available, one 1000-watt unit and three 500-watt units. Failures occurred on three of these units.

4. Three of the microphone systems had a polarization voltage capability of 28 volts only at the commencement of the program. This was found to be unsatisfactory in terms of sensitivity, and as modification units were not available, a "field-fix" to achieve 200-volt capability was adopted.

5. In FM recording of oscillatory signals, the problem of DC offset is well known, the capability of compensating for such offset at the amplifier stage was often found to be inadequate, and interchanging of the amplifier sets was necessary. Each change was followed by a recalibration of the system.

5.0 DATA ANALYSIS

For security reasons, the signature data acquired during the helicopter noise measurement program are classified as Confidential. A compilation of the reduced data and a description of the analysis methods used are therefore presented under separate cover as Volume II of this report. For completeness, however, a brief description of the analysis methods is included in this volume and illustrative examples of uncalibrated reduced data obtained by these methods are presented. It must be emphasized that these examples are not replica of the Volume II data and therefore must not be regarded as accurate representations of the noise signature of the helicopter types examined.

Two forms of analyses are discussed -- narrow bandwidth analysis of the hover noise signals, and real-time 1/3 octave band analyses of the hover and flyover noise records. A brief outline of each of these methods is given in the following subsections.

5.1 SELECTIVE NARROW BAND ANALYSIS

A typical example of the spectrum obtained by this method is shown in Figure 9. This analysis was conducted by means of a digital processing procedure based on the "Fast Fourier Transform" algorithm which allows the rapid evaluation of the discrete Fourier transform of a digitized data set. In the present applications, the program is designed to produce a power spectral density of the time function, from which the mean square value of the function in each of a series of narrow bandwidth increments is calculated and converted to sound pressure level estimates by the usual calibration and logarithmic operations. A further refinement of the program is its ability to operate on the data with a selected constant frequency resolution in each of five frequency bands, subdividing the total frequency range of interest. The chosen band limits and corresponding resolution (narrow) bandwidths employed for the helicopter noise data are given in Table V.

TABLE V. SELECTIVE BANDWIDTHS USED IN DATA ANALYSIS

Frequency Band (Hz)	Resolution Bandwidth (Hz)
0 - 500	1.6
500 - 1000	3.0
1000 - 2500	6.0
2500 - 5000	12.0
5000 - 15000	25.0

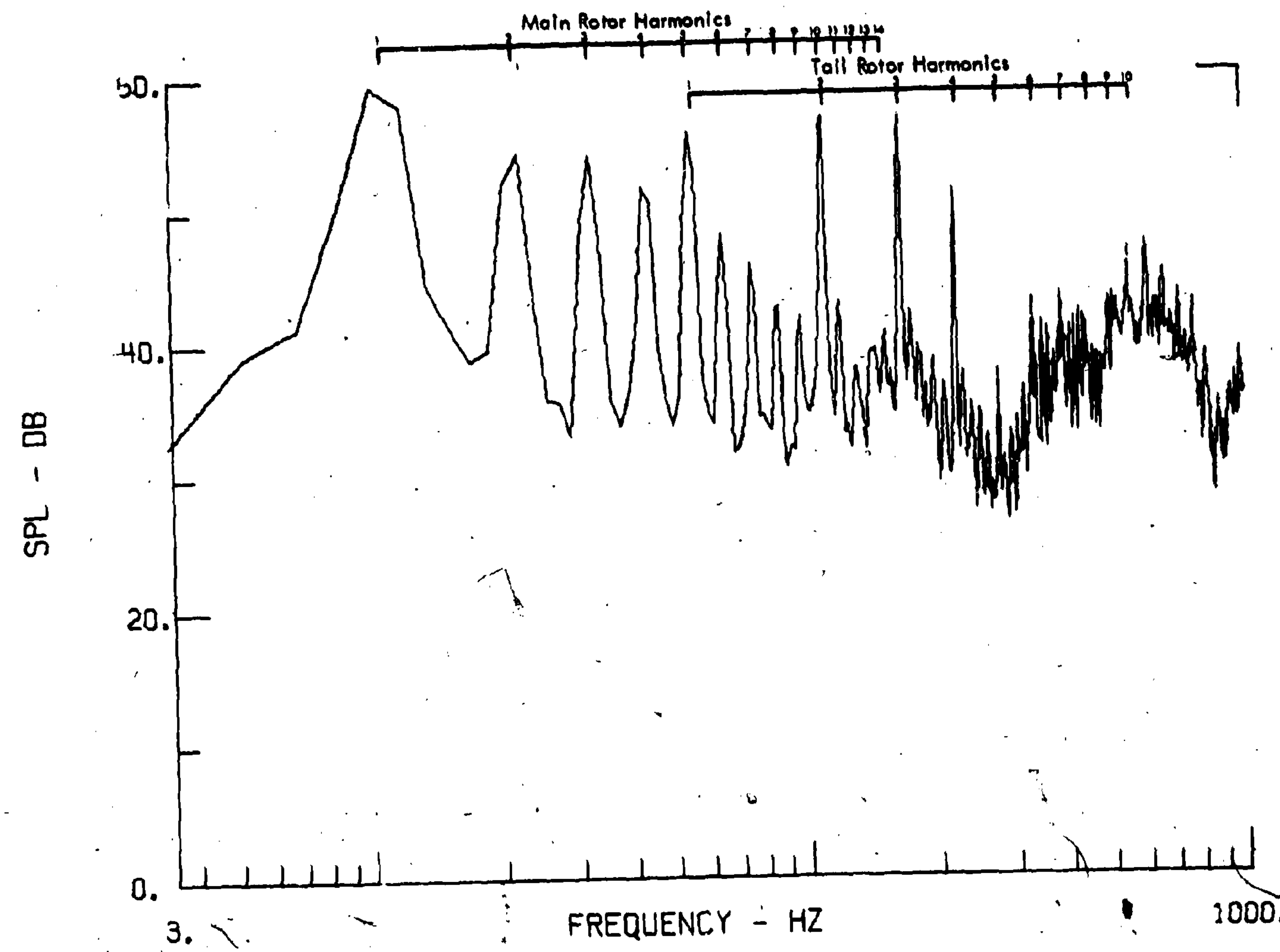

Figure 9.. Selective Narrow Band Spectrum of Helicopter Hover Noise.

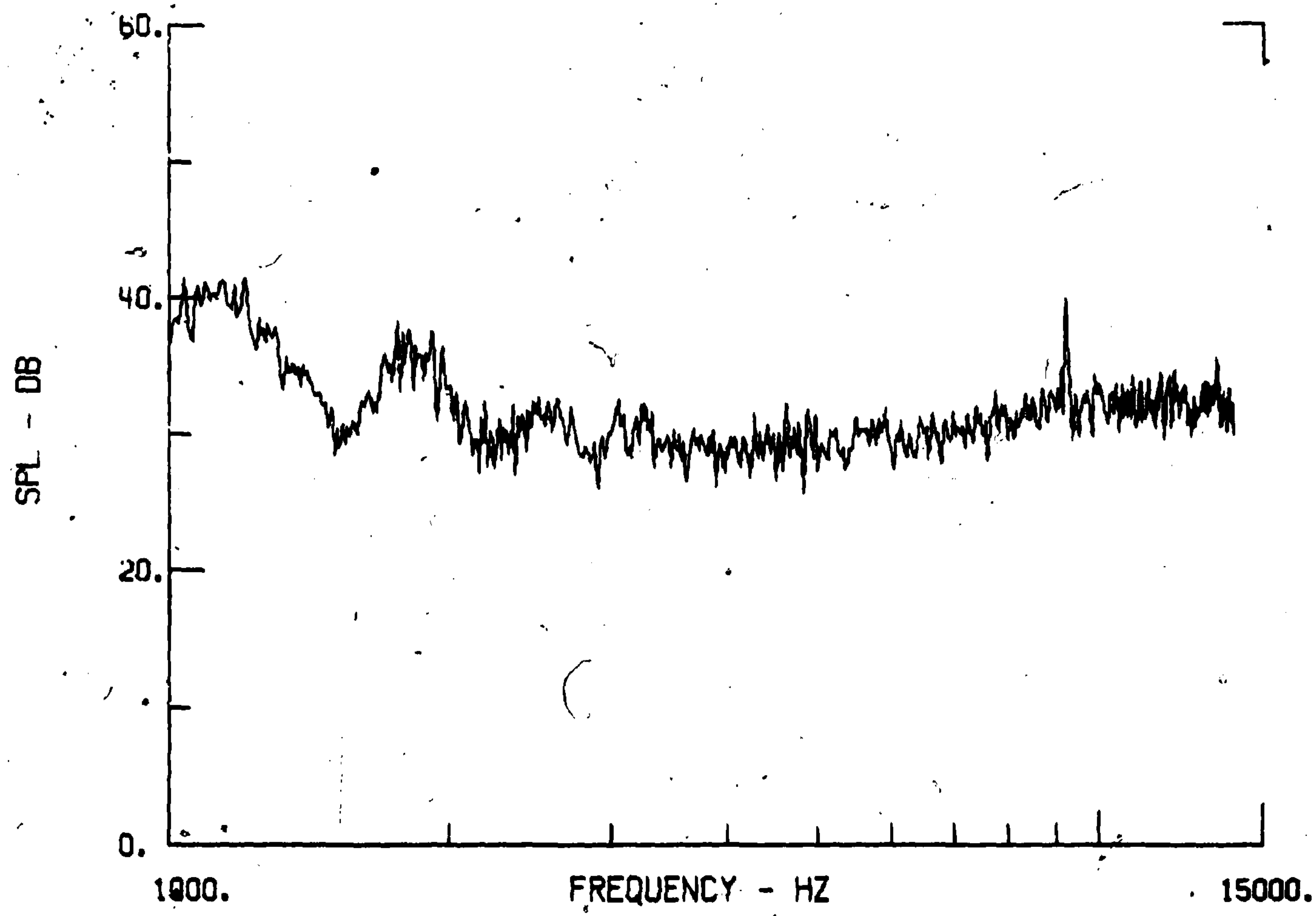

Figure 9. (Concluded).

The use of approximate octave bands to subdivide the total frequency range, and the corresponding doubling of the resolution bandwidth are inherent requirements of this particular application of the fast Fourier transform routine. However, it is notable that these requirements can be particularly well adapted to the helicopter noise analysis case where a bandwidth of the order of 3 Hz is desirable to resolve the low frequency main rotor harmonics from 10 Hz to 1000 Hz, but is unnecessary (and extravagant in terms of computation time) at higher frequencies.

The resolution bandwidth and the accuracy of the spectral estimates are dependent on the sampling (digitization) rate used in the analog to digital conversion and on the number of discrete transform points used in the digital (numerical) processing. The present program is designed such that the resolution is as specified in Table V, and the statistical accuracy of the data is maintained relatively constant over the entire frequency range. This is achieved by defining the highest sampling rate to provide the required "equivalent statistical degrees of freedom" for the analysis of the highest frequency component of interest (in the present case, 15 kHz), and by ensuring that the number of degrees of freedom is maintained constant by using the same number of transformation points in each band and by reducing the sampling rate in the lower frequency bands. The basic result of these manipulations of the numerical procedures is that the statistical degrees of freedom of the analysis are approximately equal to 10 in all bands, which gives an accuracy of within 1 dB for the harmonic content and within $\pm$ 1.5 dB for the random noise content of the spectrum. As shown in Figure 9, the analysis gives a clear indication of the predominant noise components of the helicopter noise spectrum, which are the main and tail rotor harmonics.

This method of analysis has been applied to all hover noise data records obtained at a ground radius of 2000 feet from the hover point, for each helicopter type. The resulting spectra are presented in Volume II of this report.

5.2 REAL-TIME 1/3 OCTAVE BAND ANALYSIS

In this analysis, the analog signal acquired from the magnetic tape is input to a bank of analog 1/3 octave filters covering the frequency range from 12.5 Hz to 10 kHz. The outputs of these filters are patched, in ascending frequency order, into a multiplexer-analog to digital converter which is operated in a random sampling mode at predetermined sampling rates for each frequency band. The digital data processing is then constrained to the determination of sums and sums of square of each sample set for each band. These values are then stored on tape as

an array of data representing the 1/3 octave band levels of the signal at 1/2-second real-time intervals over the desired noise record history. A secondary processing of these stored data applies the appropriate calibration and logarithmic operations to provide an output of 1/3 octave band sound pressure levels, and the overall sound pressure level calculated from these, at 1/2-second time intervals of the noise history.

In the present analysis, an additional multiplexer channel was allocated to the processing of the oscillator-code level recorded on the analog data tape to indicate the position of the helicopter along the flight path. As the oscillator signal comprised a stepped-level 1000 Hz tone, the amplitude of this tone is denoted in the real-time analysis output simply as an alphanumeric indicator and is used to define the "instants" of the reduced data records at which the aircraft was directly overhead of the ground markers, as described in Section 4.4.

This processing has been applied to 10-second time periods of the hover noise data records and to sufficiently long time intervals of the flyover noise records to provide a description of the approach and flyover noise signature of each helicopter type at each flight altitude and velocity. Typical examples of the tabulated data obtained by this analysis method are presented in Tables VI and VII for the hover and flyover cases respectively.

Complete tabulations of the real-time data have been retained for data-bank storage at the Eustis Directorate of the Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

To aid the interpretation of such real-time data obtained from microphone array measurements of flyover noise histories, a computer program was developed to evaluate and plot spatial noise contours of the data. One of these contours, obtained from helicopter noise data, is shown in Figure 10. In this illustration, the overall sound pressure level is used as the dependent variable. However, it was found that the random occurrence of transient spikes in the recorded signal content, and the effects of the helicopter noise directivity, created numerous problems in deriving a satisfactory, general, computer program that would be applicable to all helicopter types. It is considered that the contour-plot method of presenting helicopter noise data is better suited to such variables as loudness level, equivalent perceived noise level, detection distance, or other subjective evaluation scales, than to the unweighted sound pressure level which has very little interpretive potential. It is also considered that the problems encountered in the contour-plot analyses can be overcome by a more detailed study of the effects mentioned above, than was envisioned in the present scope of work.

TABLE VI. REAL-TIME ANALYZED HOVER NOISE DATA

CASE 3.1.1 AH-1G 500 FT ALTITUDE 0 KTS. MIC. NO. 1 ANGLE 0 DEG.
CALIBRATION = 1 VOLT RMS EQUIVALENCES 94.0 DB.

T	OL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
0	75	67	61	68	61	67	65	63	61	55	61	55	60	57	52	59	39	42	41	44	42	37	41	45	36	38	34	34	38	36	34	F
	74	63	50	68	60	66	64	66	61	55	61	54	60	56	49	49	42	40	40	43	47	42	44	44	36	37	35	34	35	36	35	F
1	74	61	52	68	60	66	65	65	61	52	61	54	60	57	52	58	42	41	41	44	42	40	43	41	34	35	34	35	33	34	34	F
	74	63	53	68	59	66	64	64	59	56	61	54	58	55	49	55	42	41	41	44	41	34	41	39	33	34	34	34	35	34	34	F
2	74	63	50	69	61	67	64	57	61	56	62	54	59	56	50	49	41	40	40	43	43	40	41	40	36	36	34	35	37	39	38	F
	74	65	49	69	60	67	64	63	61	55	62	56	53	57	50	47	43	43	43	45	44	38	43	41	35	35	33	33	35	34	34	F
3	75	63	48	69	61	67	64	67	62	55	61	55	59	56	51	40	45	43	45	48	46	37	44	42	36	38	34	34	34	36	38	F
	74	64	50	69	61	67	65	64	61	57	60	55	60	57	51	54	43	42	47	48	45	39	42	39	37	35	33	33	34	35	33	F
4	75	64	48	69	61	67	65	67	62	57	61	55	60	55	49	58	41	45	47	47	48	41	43	40	35	34	33	34	33	34	34	F
	75	64	51	70	62	67	64	67	62	55	62	56	62	54	50	53	41	49	50	51	44	40	40	37	36	35	33	33	35	35	33	F
5	75	64	50	70	61	67	65	64	62	57	62	56	61	54	49	52	44	47	50	47	46	41	44	42	36	38	34	35	35	35	34	F
	74	66	50	70	62	67	66	67	62	55	62	56	61	57	50	58	40	43	47	45	46	39	39	37	35	34	34	35	34	33	34	F
6	75	65	49	69	60	67	65	63	61	57	62	57	62	58	52	49	43	48	47	49	41	38	38	39	34	35	33	34	38	36	34	F
	75	65	50	69	61	66	64	66	62	58	64	55	61	56	52	48	41	46	45	45	44	38	42	40	34	35	33	35	35	35	34	F
7	74	65	48	70	61	65	64	63	60	56	63	57	60	55	52	51	40	44	48	49	41	36	37	37	34	34	33	35	34	34	34	F
	74	64	50	70	61	66	62	64	59	55	63	56	61	56	52	47	39	41	44	47	43	37	39	38	34	35	33	34	36	35	34	F
8	75	64	51	70	62	67	63	67	61	54	62	56	62	57	52	50	42	43	48	45	42	38	37	37	34	35	34	35	34	35	35	F
	74	64	49	70	61	65	63	64	59	55	62	56	62	58	55	51	42	45	43	42	42	39	39	38	34	34	33	35	34	35	34	F
9	75	64	49	70	61	67	64	65	63	57	62	56	60	58	56	51	43	43	46	47	43	42	40	39	35	35	34	35	36	34	35	F
	75	64	49	70	62	66	62	63	60	56	61	55	60	60	56	57	41	42	45	44	44	39	38	38	35	35	34	35	33	35	35	F
10	75	63	50	71	62	67	64	67	62	55	61	56	61	58	52	54	43	44	43	46	47	42	39	41	38	34	33	34	37	37	42	F

NSTOP

TABLE VII. REAL-TIME ANALYZED FLYOVER NOISE DATA

T	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	A	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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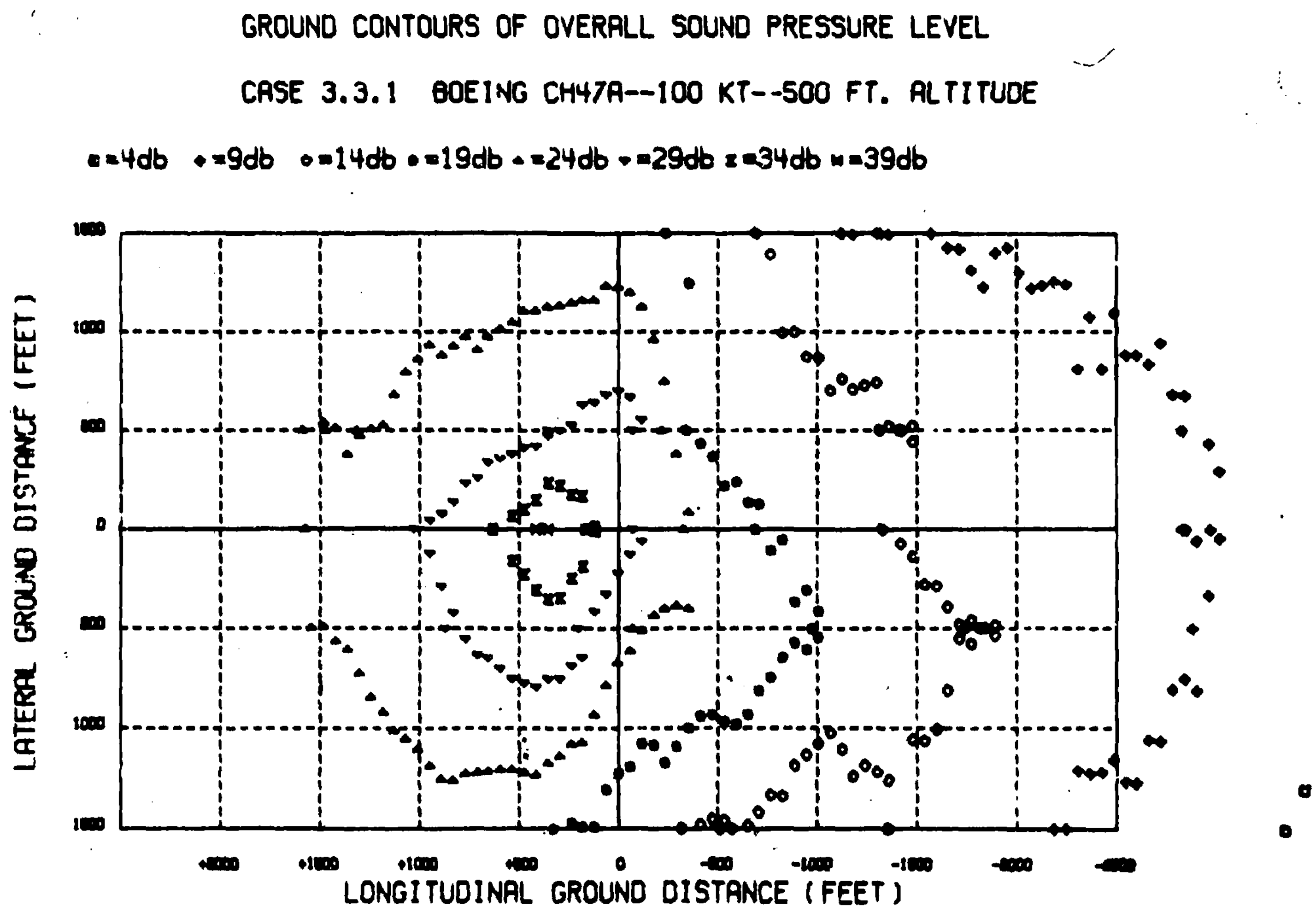

Figure 10. Contour Plot of Real-Time Analyzed Flyover Noise Levels.

6.0 SUMMARY

A review of acoustic instrumentation and noise measurement requirements has been conducted to determine a practical, standardized approach to the acquisition of noise data of Army helicopters. Based on this review, a preliminary noise measurement procedure was defined and applied in a test program for the acquisition of noise data from five Army helicopters. The tests were conducted for hover and flyover modes of operation of each helicopter. Three methods of data analysis have been applied to the noise records, and typical results are included in this volume. These analyses were (1) narrow band spectral analysis of hover noise records, (2) real-time 1/3 octave band analysis of both hover and flyover noise data, and (3) ground-plane contour plotting of the real-time analysed, flyover noise data. Of these, only the contour plotting was found to be problematic for helicopter noise data due to more frequent fluctuations of the overall sound level histories than were expected. The data obtained by the 1/3 octave band and narrow band analyses, and the magnetic tapes containing the original sound recordings, are retained for storage at the Eustis Directorate.

As a result of the reviews and field tests conducted during this program, a draft acoustic measurement specification for baseline noise measurements of Army helicopters has been compiled. This draft specification is presented in full in Section 7.0 of this report.

7.0 DRAFT ACOUSTIC MEASUREMENT SPECIFICATION FOR BASELINE NOISE MEASUREMENT OF ARMY HELICOPTERS

7.1 PURPOSE

The purpose of this specification is to define basic procedural requirements in the measurement of Army helicopter noise data, such that the data obtained from different programs will be comparable in accuracy and compatible in acquisition and storage format. It is the intention of this specification to allow sufficient flexibility in the procedural requirements to permit advanced instrumentation techniques to be employed, as they become available. The specification is therefore aimed at such aspects of field noise measurements as determine the capability of direct comparison of data obtained from different helicopters in various flight modes. Recommendations on data analysis are made only with respect to providing a basic reduced-data compilation for storage with the analog recording tapes. These reduced data are not intended to be a complete interpretable description of the helicopter noise field. It is intended that they will provide an accurate assessment of the 1/3 octave band frequency content of each of the acquired noise records, which may be used as a comparative check on later detailed analyses, or corrected for atmospheric conditions for use in later noise evaluations based on such 1/3 octave band data.

The following requirements are the BASIC and MINIMUM requirements of field measurement programs to acquire Army helicopter noise data for repository storage at the Eustis Directorate of the Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. Additional requirements on data acquisition, directed toward the needs of specific research or monitoring applications, are not considered in this document and will be specified separately for each measurement program.

7.2 GENERAL DESCRIPTION

The following items of noise measurement procedures are covered by this document:

1. Basic measurement equipment, placement at the measurement site, system calibration and field signal calibrations, required system accuracy

2. Helicopter hover and flyover flight conditions, noise data monitoring and recording requirements, helicopter tracking methods and synchronization with noise data

3. Flight identification and site meteorological data requirements

4. Analysis requirements for basic repository storage of reduced data

5. Storage format of noise and identification data.

7.3 FIELD MEASUREMENT EQUIPMENT

7.3.1 Microphone Systems

A minimum of five microphone systems will be employed to acquire noise data at five remote field stations. Each microphone system will be comprised of:

1. A microphone assembly capable of measuring helicopter noise within desired accuracies, as specified in Section 7.3.4.

2. A tripod or similar provision for mounting the microphone at a height of approximately 4 feet above ground level.

3. A microphone windscreen with minimum interference effects on the grazing-incidence sound measurement capabilities of the microphone system. Corrections for any insertion loss produced by the windscreen must be defined as a function of frequency for grazing incidence sound impingement.

4. An acoustic calibrator unit to supply an acoustical input of known amplitude and frequency to the microphone transducer element.

5. Signal-carrying equipment (cable or other) to provide a means of transmitting the acquired (noise) analog signal to suitable monitoring, conditioning and recording facilities while retaining the required overall measurement accuracies and capabilities.

7.3.2 Signal Conditioning and Recording Systems

1. The sound produced by the aircraft will be recorded in such a

manner that a complete time history of each measured sound signal, within the frequency and amplitude limits specified in Section 7.3.4 and 7.4.4, is retained on magnetic tape.

2. Single carrier FM recording will be used for each sound signal, with Intermediate Band electronics and 60 ips tape transport speed in compliance with IRIG Telemetry Standards Document 106-69 (revised February, 1969).

3. A gain/attenuation system will be used to provide a suitable adjustment of each signal level input to recorder such that the recording accuracy is retained throughout the sound history, as specified in Sections 7.3.4 and 7.4.4.

4. Signal monitoring equipment will be used to ensure that sensing and recording accuracies are maintained during the noise measurement program.

5. At least two of the noise records will also be conditioned by pre-emphasis of frequencies about 1000 Hz, by one of the following methods:

   (a) A frequency-linear gain adjustment of a branched, high pass filtered content of the signal.

   (b) A frequency-weighted gain adjustment of the basic signal prior to recorder input.

   Each of the above methods must allow for corresponding de-emphasis of the signals, on reproduction, by commercially available equipment.

6. A means of recording an IRIG B standard time code will be employed for synchronization of helicopter noise and flight position tracking data.

7.3.3 Calibration

1. Each microphone will be calibrated for grazing incidence response, over a frequency range of 5 Hz to 15 kHz, according to ASA Standard S1.10 - 1966, ~~or~~ the latest revision thereof.

2. The complete measurement and recording system must be subjected to a frequency and amplitude electrical calibration by the use of a swept-frequency sinusoidal insert voltage, over

the range 5 Hz to 15 kHz, at known levels covering the expected measurement dynamic range. The signal input at each microphone assembly will be transmitted through the system (including field cables) and will be recorded on magnetic tape for system accuracy verification purposes.

3. Immediately prior to and after each test period, and at least once on each noise data magnetic tape, an acoustic calibration signal will be recorded in the field for the purposes of checking system sensitivity and to provide an acoustic reference level for analysis of the sound data.

4. The ambient noise, including both acoustical background and electrical noise of the measurement system, must be recorded in the test area with the system gain set at levels appropriate to the helicopter noise measurement range.

7.3.4 System Accuracy

1. The frequency response of each microphone to a sensibly plane progressive sinusoidal wave of constant amplitude, at grazing incidence to the microphone face, must lie within the following limits:

   10 Hz to 19 kHz, linear $\pm$ 1 dB.
   5 Hz to 15 kHz, linear $\pm$ 2 dB

   for sound pressure levels in the range 50 to 120 dBSPL.

2. Windscreen correction factors must be predetermined as a function of frequency to an accuracy of within $\pm$ 1 dB for grazing incidence sound field impingement.

3. Each complete assembly of noise measurement and recording equipment (including cable) will have an electrical frequency response linearity of within

   $\pm$ 2 dB from 5 Hz to 15 kHz

   for a range of signal voltage levels corresponding to input sound levels of 50 dB to 120 dBSPL at the microphone sensor.

4. The total harmonic distortion of the sound sensing microphone equipment will not exceed 1% over the required measurement dynamic range.

5. The total harmonic distortion of the assembled noise measurement and recording equipment will not exceed 4% over the required measurement dynamic range.

7.4 FIELD MEASUREMENT TECHNIQUES

7.4.1 Test Site Conditions

1. Locations for measuring noise from the helicopter in flight must be surrounded by relatively flat terrain having no excessive sound absorptive or obstructive characteristics (such as tall buildings or trees) between the aircraft and sound sensing equipment, within the measurement flight path range. Significant sound reflection from equipment accessories or nearby buildings must be avoided at the microphone locations.

2. The tests must be carried out under the following weather conditions:

   (a) No rain or other precipitation.

   (b) Relative humidity not higher than 90% or lower than 30%.

   (c) Ambient temperature not above 86° F and not below 41° F at 10 meters above ground.

   (d) Wind velocity not above 10 kts at each microphone unit, and cross wind component not above 5 kts at 10 meters above ground level.

   (e) No temperature inversion or anomolous wind conditions that would significantly affect the noise level of the aircraft as measured at each microphone location.

   (f) No excessive wind conditions at flight altitude that would significantly affect the performance and yaw condition of the helicopter in hover and flyover operations.

7.4.2 Helicopter Flight Conditions

1. Noise measurements are required for hover and flyover modes of operation.

2. Helicopter noise measurements should be obtained for flyover altitudes of 200 feet, 500 feet, and 1000 feet.

3. Two flyover velocities should be examined at each altitude. Preferred velocities are 60 or 70 knots and 100 or 150 knots, respectively, whichever best approximates to 60% and 100% of maximum range cruise condition.

4. The minimum straight and level flight range, over which noise measurements will be obtained, should be 15,000 feet. The minimum straight and level approach distance should be 10,000 feet, relative to the center of the microphone array. A pass range of at least 3,000 feet is preferred.

5. Hover noise measurements should be conducted at two altitudes. Altitudes of 500 feet and 1000 feet are preferred. At each hover altitude, the aircraft should attain eight orientations relative to a chosen reference.

7.4.3 Microphone Arrays

The following arrangements of microphones at the measurement site will be employed for basic helicopter noise data acquisition purposes. Each microphone should be supported at a height of approximately 4 feet above ground level. The orientation of each microphone should be such that the direct radiated noise field of the helicopter will impinge at grazing incidence to the microphone, for all positions along the flight path. The microphones will be protected from wind effects for local wind velocities in excess of 6 knots.

1. Hover Array - A minimum array of five microphones is required for hover noise measurement programs. Three of these should be located on a ground radius of 2000 feet from the hover point at 0-, 15-, and 30-degree angles to a chosen reference through the hover point. Two microphones should be located at one other radius, at angles of 0 degree and 22.5 degrees from the reference.

2. Flyover Array - A minimum array of five microphones is required in flyover noise measurement programs. The flyover array should be centered along a line normal to the flight ground-trace. The center microphone should be positioned directly under the flight path. Two microphones will be displaced on each side of the center unit by a distance of 500 feet and 1500 feet from the center, respectively.

7.4.4 Data Acquisition Procedures

1. All noise data should be measured and recorded by procedures which ensure that maximum utilization is made of the available frequency response range (5 Hz to 15 kHz) and system dynamic range, within the system accuracies specified in Section 7.3.4.

2. An IRIG B standard time code should be recorded on one channel of each noise data tape during the noise data recordings. This time code will be synchronized with helicopter position tracking data.

3. Flyover noise data should be recorded over a flight path distance of at least 10,000 feet approach and 3000 feet pass.

4. Hover noise data should be recorded for a minimum period of 30 seconds at each flight orientation.

5. Field calibration signals of known level and frequency will be recorded on each data recording tape.

6. The noise signal data will be recorded in such a manner that the maximum peak amplitude of the signal does not exceed the "clipping" and other distortion limits of the recording equipment.

7.4.5 Helicopter Tracking

1. The aircraft height and flight path position relative to a central (reference) point at the microphone array must be determined by a method independent of normal flight instrumentation, such as radar tracking or photographic scaling techniques to be approved by the Eustis Directorate.

2. The helicopter position along the flight path in flyover operations will be time-related to the noise recorded at each noise recording station by means of a synchronization signal comprising a standard IRIG B Time Code. An additional coding may be used to supplement the Standard Code, if necessary; and when employed, it must be described in detail with relation to the noise and tracking data.

7.5 DATA ANALYSIS

1. The basic data analysis will consist of a one frequency analysis of each of the recorded acoustical signals, using 1/3 octave band filters complying with the recommendations given in International Electrotechnical Commission (IEC) Publication No. 225 entitled "Octave, Half-Octave and Third-Octave Band Filters Intended for the Analysis of Sound and Vibrations".

2. A set of 30 consecutive 1/3 octave band filters must be used. The first filter of the set will be centered at a geometric mean frequency of 12.5 Hz, and the last of 10 kHz.

3. A single value of the rms level must be provided every 0.5 ± 0.01 second for each of the 30 1/3 octave bands. Each rms value will be obtained by time averaging over a minimum of 0.4 second of each 0.5 second period. An overall level will be obtained either by direct processing of the unfiltered signal or by summation of the 1/3 octave band levels, at each 0.5 second interval.

4. The analyzer device must have a minimum crest factor capacity of 7 and shall measure, within a tolerance of ± 1 dB, the true rms level of a steady sinusoidal signal in each of the 30 1/3 octave bands.

5. Each output level from the analyzer will be converted to sound pressure level referenced to .0002 microbar rms.

6. The dynamic range capability of the analyzer for output of a single helicopter noise 0.5 second period spectrum must be at least 50 dB between full-scale output level and the maximum noise level of the analyzer equipment.

7. The complete analyzer system must be subjected to a frequency and amplitude electrical calibration by use of sinusoidal or broadband signals covering the range of 11 Hz to 11,200 Hz frequency and a range of known amplitudes representative of the input signal data levels. If broadband signals are used, they must be described in terms of their average maximum rms values for a non-overload condition.

7.6 IDENTIFICATION OF NOISE DATA

1. Meteorological data pertaining to conditions at the

measurement site should be logged at intervals of one hour during each period of noise measurement. These data will include temperature, barometric pressure, relative humidity, and wind velocity and direction.

2. Flight Instrumentation Data pertaining to flight and propulsion system operating conditions should be logged for each noise acquisition flight. These data will include, if available, basic vehicle weight, fuel weight, weight of crew and accessory equipment, rotor speeds, engine operating speeds and pertinent temperature data.

3. Each record of each noise data recording tape will be identified by voice narration on a full tape track (not edge-track). This identification will include helicopter type, mode of operation, altitude and velocity. The calibration levels and gain adjustments will also be recorded on tape.

4. All information pertinent to the noise measurement conditions and flight operations will be documented by means of a "tape-log" report. These will include the above mentioned meteorological, flight instrumentation and noise data identification data.

5. Analyzed data will be printed in tabular format as filtered and overall levels at each 0.5 second interval of the recorded sound histories. A means of relating each interval of noise data with flight path position of the helicopter will be presented in the tabulated data.

6. The type of equipment used for measurement and analysis of all acoustic data must be reported.

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